Contract No. NAS9-17102
30 November 1984

CR- 171 834
C.1

Design Concept Definition Study For An Improved Shuttle Waste Collection Subsystem

Final Report

(NASA-CR-171834) DESIGN CONCEPT DEFINITION STUDY FOR AN IMPROVED SHUTTLE WASTE COLLECTION SUBSYSTEM Final Report (General Electric Co.) 326 p HC A15/MF A01 CSCL 06K

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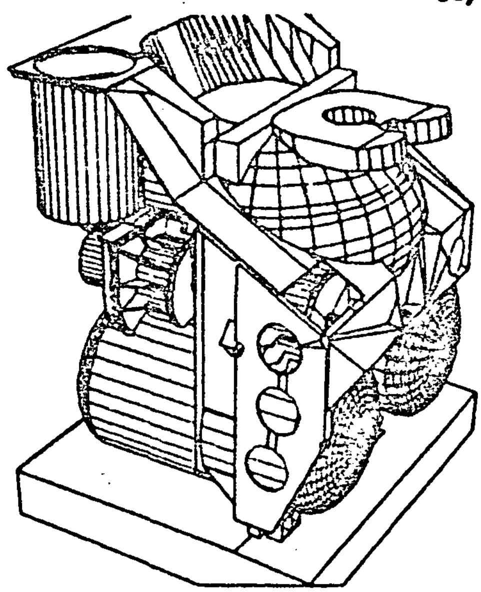

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Refer: GEH-(0)-6913 November 30, 1984

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

Attention: Nancy Steel, BE2
Contract Specialist

Subject: Contract No. NAS9-17182
Design Concept Definition Study
Waste Collection Subsystem
Final Report - Submittal Hereof

Dear Ms. Steel:

In accordance with the subject contract, enclosed please find the Final Report. Please note that the System Requirements Definition Document for an improved Waste Collection Subsystem is included as Appendix A.

We anticipate your comments regarding this submittal hopefully before year's end. Your cooperation in regards to this matter is greatly appreciated.

Should you have any questions, please do not hesitate to contact me.

Very truly yours,

T. D. Gregory

T. D. Gregory
Contract Administrator

TDG/sm
Enclosure

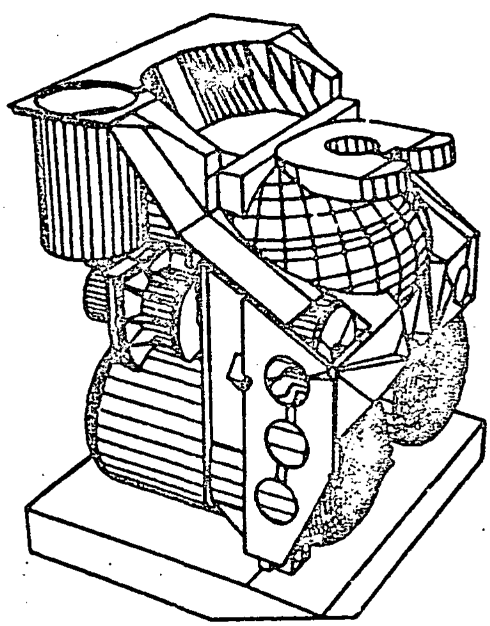
cc: Gene Winkler, EC3 (25 ea)
Tech. Library, JM2 (1 ea)
Tech. Utilization Office, AT3 (1 ea)

Design Concept Definition Study For An Improved Shuttle Waste Collection Subsystem

Final Report

Contract No. NAS9-17182

30 November 1984



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Prepared for:
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas

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SECTION 1

SUMMARY/RECOMMENDATIONS

General Electric Space Systems Division provides a no-risk approach for developing an Improved Waste Collection Subsystem (WCS) for the Shuttle orbiter. The GE Improved WCS Concept builds on the experience of 14 Shuttle missions with over 400 man-days of service. This concept employs the methods of the existing flight-proven mature design, augmenting them to eliminate foreseen difficulties and to fully comply with the design requirements. Finally, the GE Improved WCS provides a prototype for Space Station applications, fully satisfying its known requirements.

The GE Improved WCS Concept includes separate storage for used wipes. Compaction of the wipes provides a solution to the capacity problem, fully satisying the 210 man-day storage requirement. The added feature of in-flight serviceable storage space for the wipes creates a variable capacity feature which affords redundancy in the event of wipes compaction system failure. Addition of features permitting in-flight servicing of the feces storage tank creates a variable capacity WCS with easier post-flight servicing to support rapid turnaround of the Shuttle orbiter. When these features are combined with a vacuum pump to evacuate wipes and fecal storage tanks through replaceable odor/bacteria filters to the cabin, the GE Improved WCS satisfies the known requirements for Space Station use, including no venting to space. Orbiter venting to space remains to provide increased system reliability through redundant capability.

The proposed concept permits piecemeal or total development depending upon the funding available, acceptance of each proposed feature, and the perceived need to test one feature prior to proceeding with another.

Testing of proposed features in conjunction with the existing WCS results in a no-risk approach in which each feature can be tested prior to its incorporation into the baseline design.

Section 3.1.1 of the System Requirements Definition Document for an Improved Waste Collection Subsystem (Appendix A of this report) gives a more detailed description of the concept, its features, and its operation. This GE concept builds upon the experience of the existing design to fully satisfy the design requirements, ease operation and servicing, increase user satisfaction, eliminate the foreseen difficulties, and even satisfy Space Station requirements. The resulting concept is ready for NASA approval for development of the detailed design, test plans, and test articles.

SECTION 2

INTRODUCTION

The Design Concept Definition Study for an Improved Shuttle Waste Collector Subsystem was undertaken to develop a design concept for improved waste collection that resolved the in-flight usage problems being encountered with the existing waste collection subsystem (WCS) and which could be a precursor for the Space Station WCS. At the outset of the study, the WCS baseline design included:

- o Air flow to separate and collect the metabolic wastes
- o Transfer of collected urine to a waste water storage tank
- o An electrically driven slinger (high speed motor) to direct the separated feces for collection against the side of the container for vacuum drying of the feces.

In-flight use of the WCS had experienced only limited success at the outset of the study. The primary problem was considered to be with feces collection. Several contracts were let by NASA to develop an optimum improved concept which could be developed as an orbiter flight test article for concept verification and subsequent production of new flight hardware.

The General Electric Company study reviewed the existing WCS design and operating experience, developed possible improvements to the existing design, and identified design limitations. Eagle Engineering, Inc. assisted with this effort and their results were presented to GE (Appendix E) and documented in a report (Appendix D). Incorporating the Eagle results, GE conceptualized alternative solutions to the capacity problem for the Mid-Term Status Review (Appendix C) which was conducted with NASA review and comment.

GE developed representative implementations of the alternative concepts, performed trade-off studies of these candidate configurations, and selected the optimum configuration for the final presentation to NASA (Section 3). The System Requirements Definition Document for the optimum configuration is presented in Appendix A and other relevant issues are addressed in Appendix B.

During the course of the study, the Shuttle orbiter WCS baseline design changed, eliminating the slinger, and the new configuration experienced satisfactory operation. The GE study included consideration of this success and the options were traded-off after the mid-term presentations. Recommendations for implementation of the GE Improved WCS were developed to reduce any risk to continued successful system operation while the optimum concept is tested and incorporated.

SECTION 3

FINAL PRESENTATION

This section represents the final presentation as presented by the General Electric Company to NASA on 1 November, 1984, as part of NASA Contract Number NAS9-17182.

HOUSTON OPERATIONS

SPACE SYSTEMS DIVISION

IMPROVED WASTE COLLECTION SYSTEM STUDY

FINAL PRESENTATION

1 NOVEMBER 1984

GENERAL ELECTRIC COMPANY

SPACE SYSTEMS DIVISION

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HOUSTON OPERATIONS

SPACE SYSTEMS DIVISION

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SPACE SYSTEMS DIVISION

IMPROVED WASTE COLLECTION SYSTEM STUDY

INTRODUCTION

- STUDY OBJECTIVES AND END PRODUCTS
- STUDY OVERALL WORK FLOW
- CONTRACT SCHEDULE

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STUDY OBJECTIVES AND END PRODUCTS

This chart presents the objectives of the study and the end products. The objectives and end products were accomplished, the System Requirements Definition Document for an Improved Waste Subsystem appearing as Appendix A to this report.

STUDY OBJECTIVES AND END PRODUCTS

OBJECTIVES

- DEVELOP A DESIGN CONCEPT FOR IMPROVED WASTE COLLECTION THAT RESOLVES IN-FLIGHT USAGE PROBLEMS FOR THE SHUTTLE ORBITER AND WHICH COULD BE A PRECURSOR FOR SPACE STATION.
- PROVIDE BASIS FOR SELECTION OF AN OPTIMUM CONCEPT WHICH COULD RESULT IN DEVELOPMENT OF AN ORBITER FLIGHT TEST ARTICLE FOR CONCEPT VERIFICATION AND SUBSEQUENT PRODUCTION OF NEW FLIGHT HARDWARE.

END PRODUCTS

- PRESENTATION TO NASA OF A DESIGN APPROACH IN SUFFICIENT DETAIL TO PERMIT SELECTION OF AN OPTIMUM CONCEPT FOR FLIGHT TEST ARTICLE DEVELOPMENT.
- FINAL STUDY REPORT AND SYSTEM REQUIREMENTS DEFINITION DOCUMENT.

IMPROVED WCS STUDY OVERALL WORK FLOW

This chart presents the Improved WCS Study work flow as presented in the proposal.

The work flow was slightly modified during the performance of the study, as additional data became available on the performance of the current Waste Collection Subsystem and its impacts on the study work flow were implemented.

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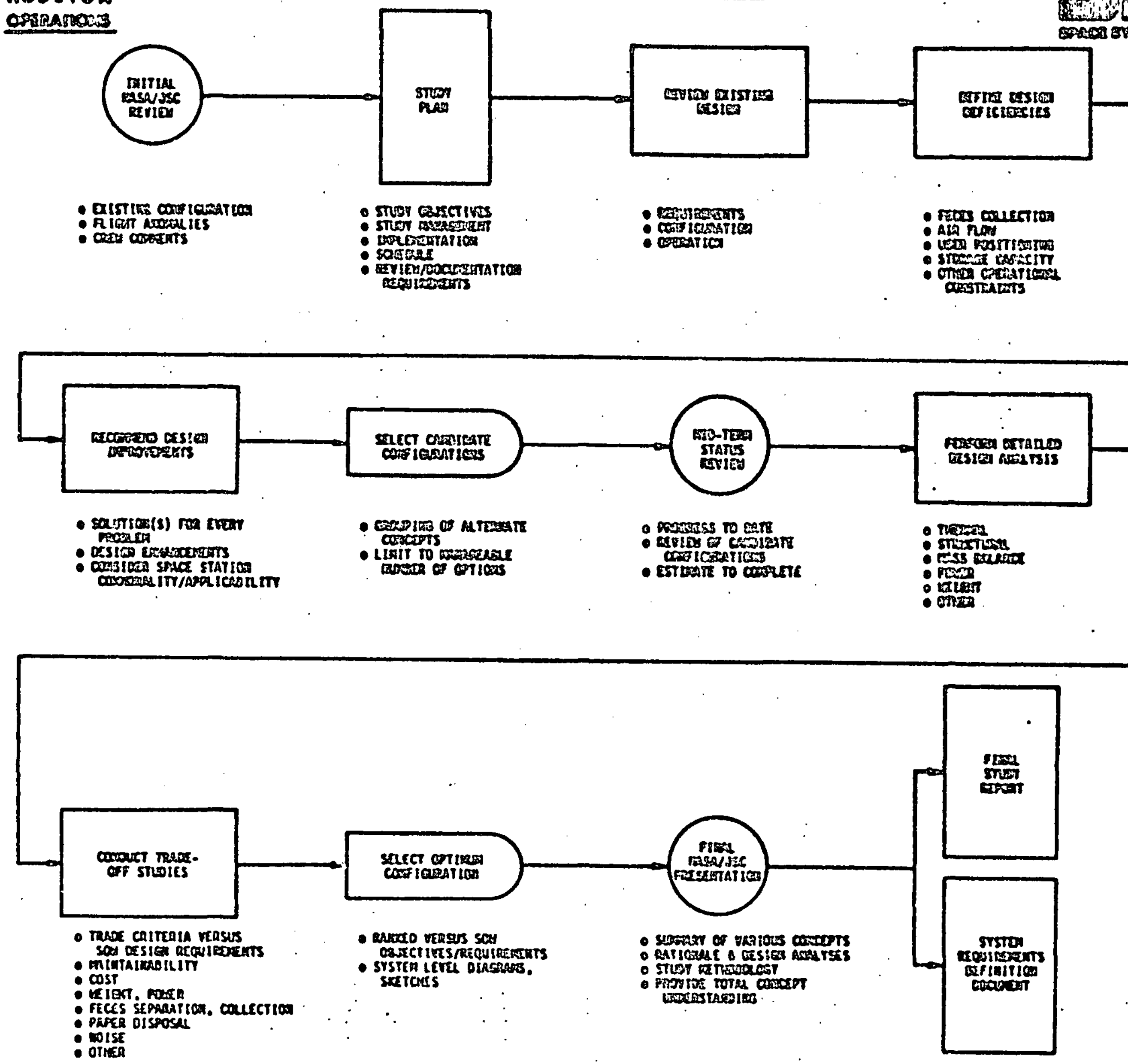
IMPROVED WCS STUDY OVERALL WORK FLOW



CONTRACT SCHEDULE

This chart presents the schedule for this contract, NAS9-17182. Schedule milestones were achieved throughout the contract.

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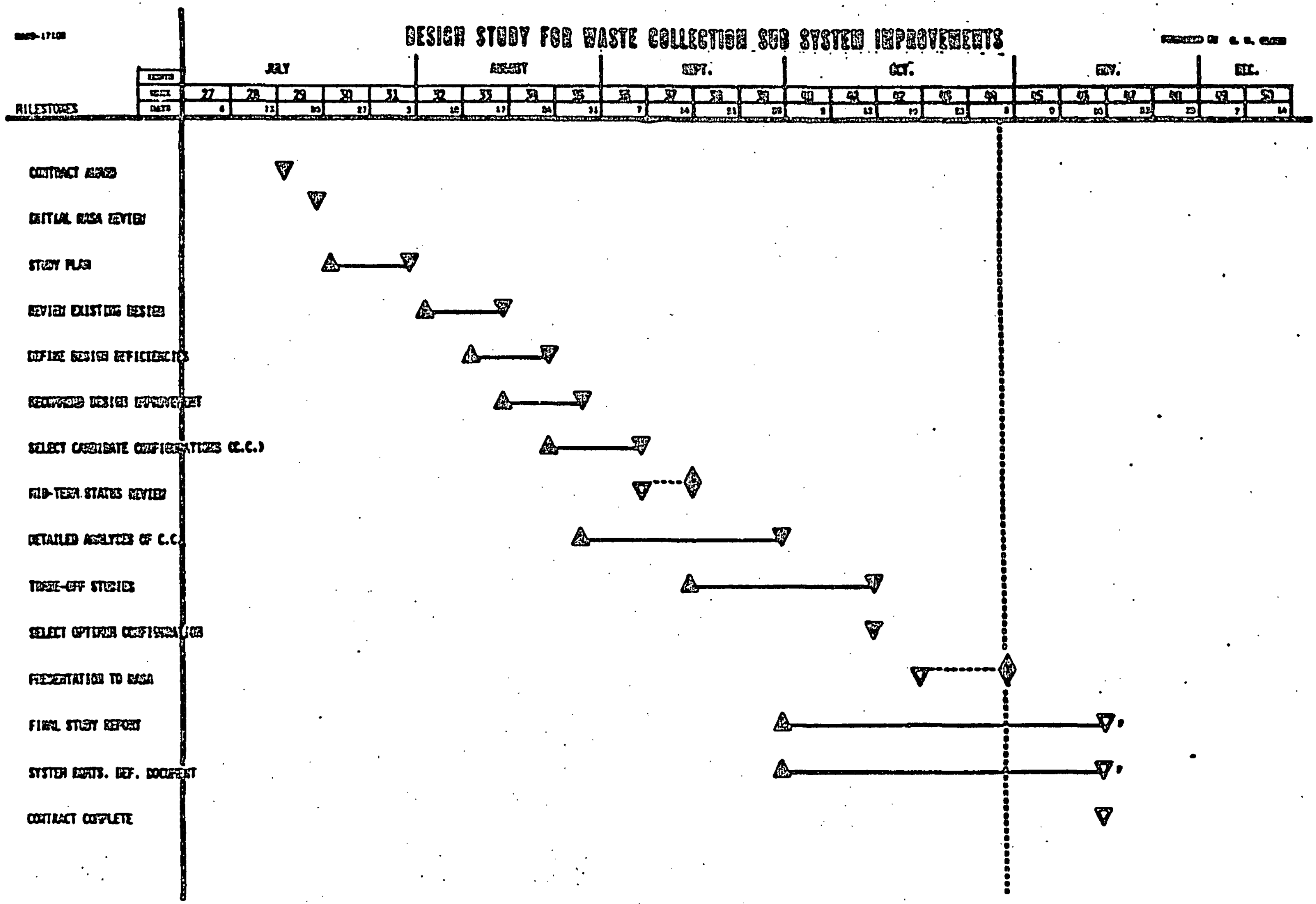
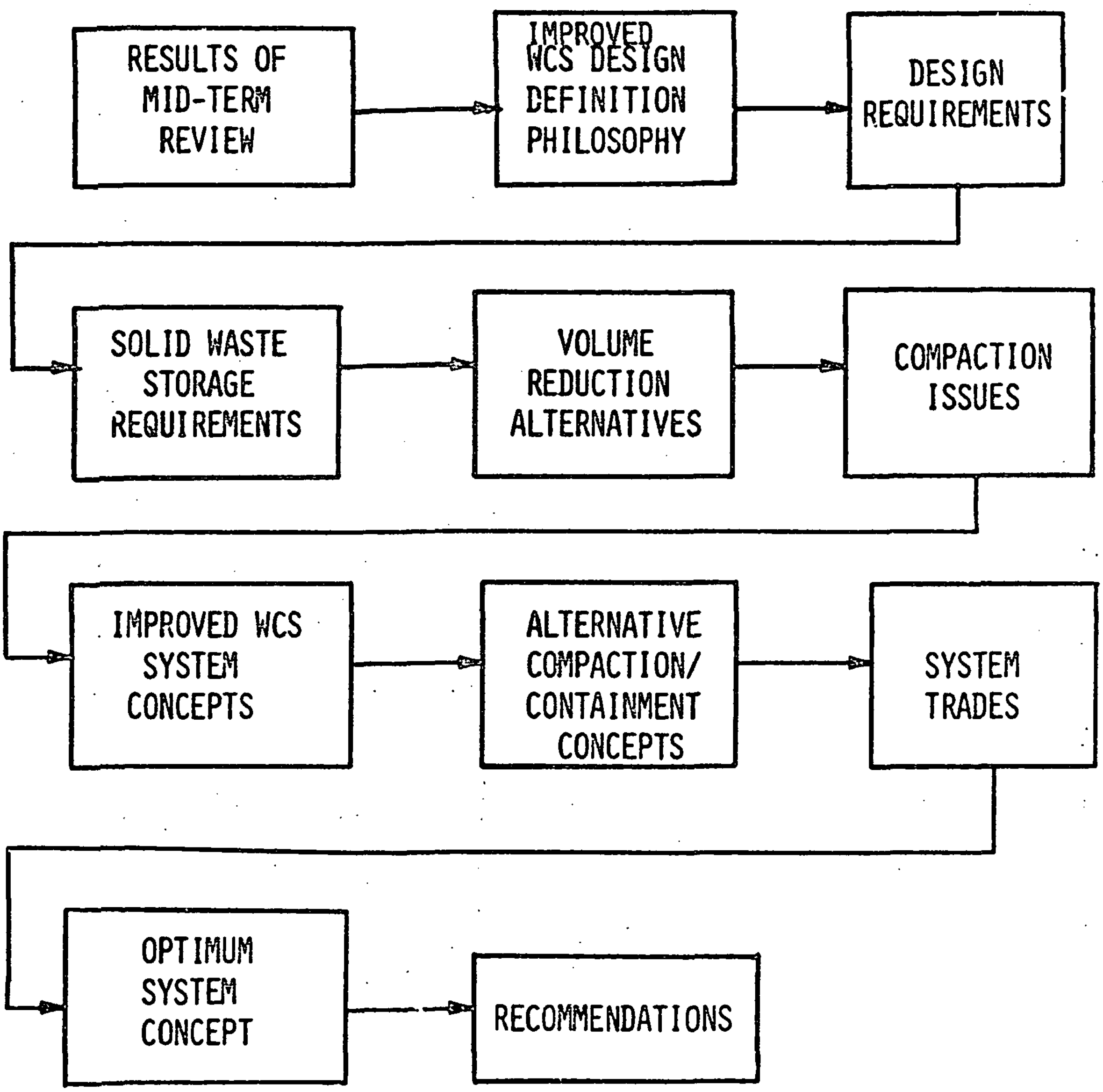


FINAL PRESENTATION FLOW

The flow of the technical portion of the final presentation is presented in this chart. The results presented at the mid-term status review on 14 September, 1984 are reviewed, and an improved WCS design philosophy is established. The SOW design requirements are considered, and the solid waste storage requirements are identified. The need for solid waste volume reduction is established, and alternatives for accomplishing this are identified, traded, and compaction is identified as the most viable methodology. Issues and concerns with compaction are discussed, and system impacts are established. The Improved WCS System concept is identified, and alternative compaction/containment concepts are established. System trades are performed, other system level issues are identified, and an optimum system concept is evolved. This concept is presented in greater detail, and conclusions and a recommended development process are presented.

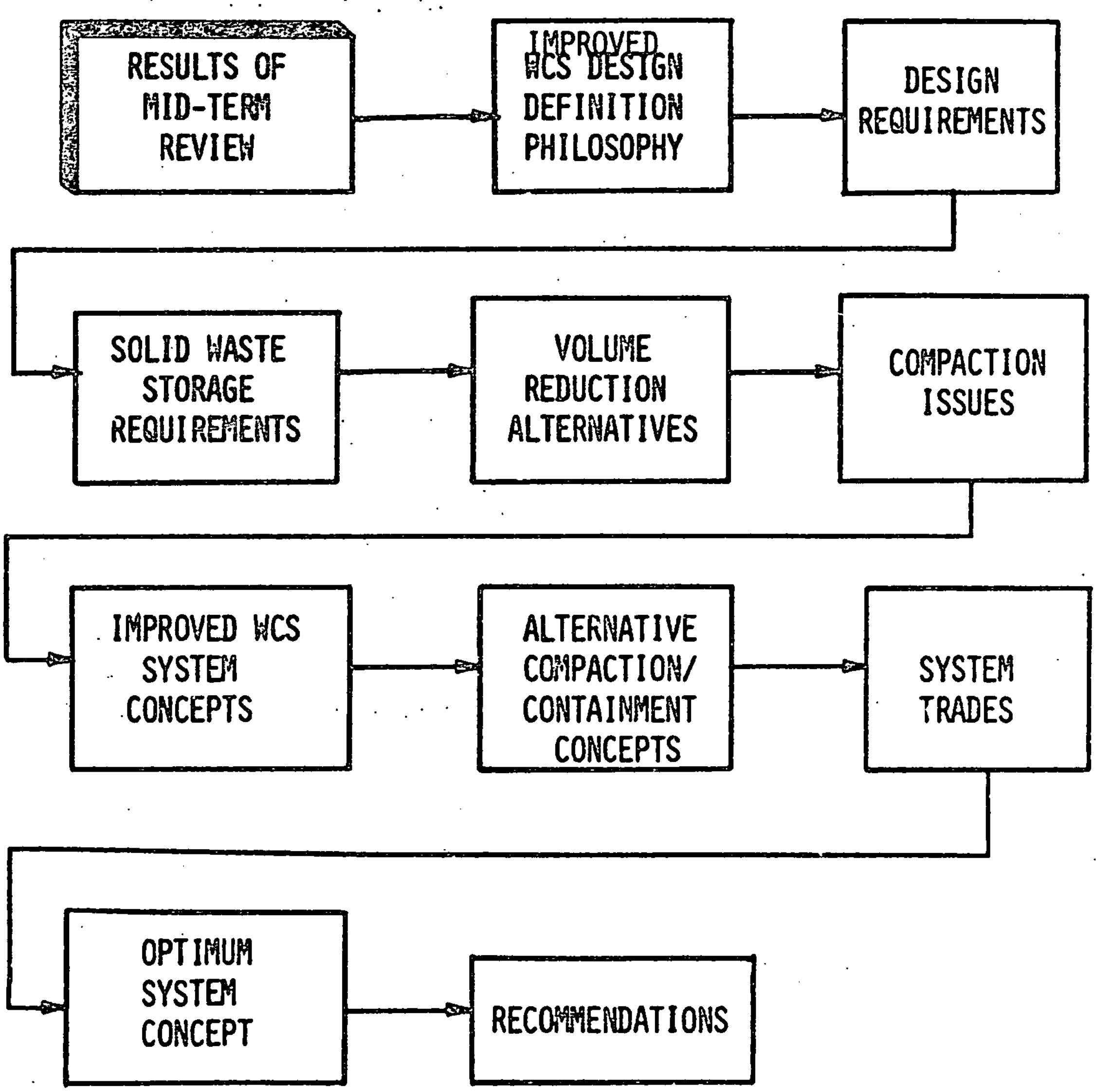
FINAL PRESENTATION FLOW



RESULTS OF MID-TERM REVIEW

The following section summarizes results presented at the mid-term review. The mid-term review presentation appears as Appendix C of this report, and the Eagle Engineering mid-term report and presentation appear as Appendices D and E, respectively.

FINAL PRESENTATION FLOW



RESULTS OF THE MID-TERM REVIEW

This chart identifies the design limitation of the current WCS as presented at the General Electric Company Mid-Term Status Review on 14 September, 1984. This limitation, identified as "the paper problem", relates to the foreseen inability of the current system to accommodate 210 man-days of fecal waste and all cleansing wipes.

Total elimination of wipes through the usage of a "wet" John (water cleansing and/or separation) were considered to possess too high a design risk, significantly more complex, and too user unfriendly to be implemented for an Improved WCS and all concepts using this separation/cleansing methodology were eliminated.

Options for paper containment are presented:

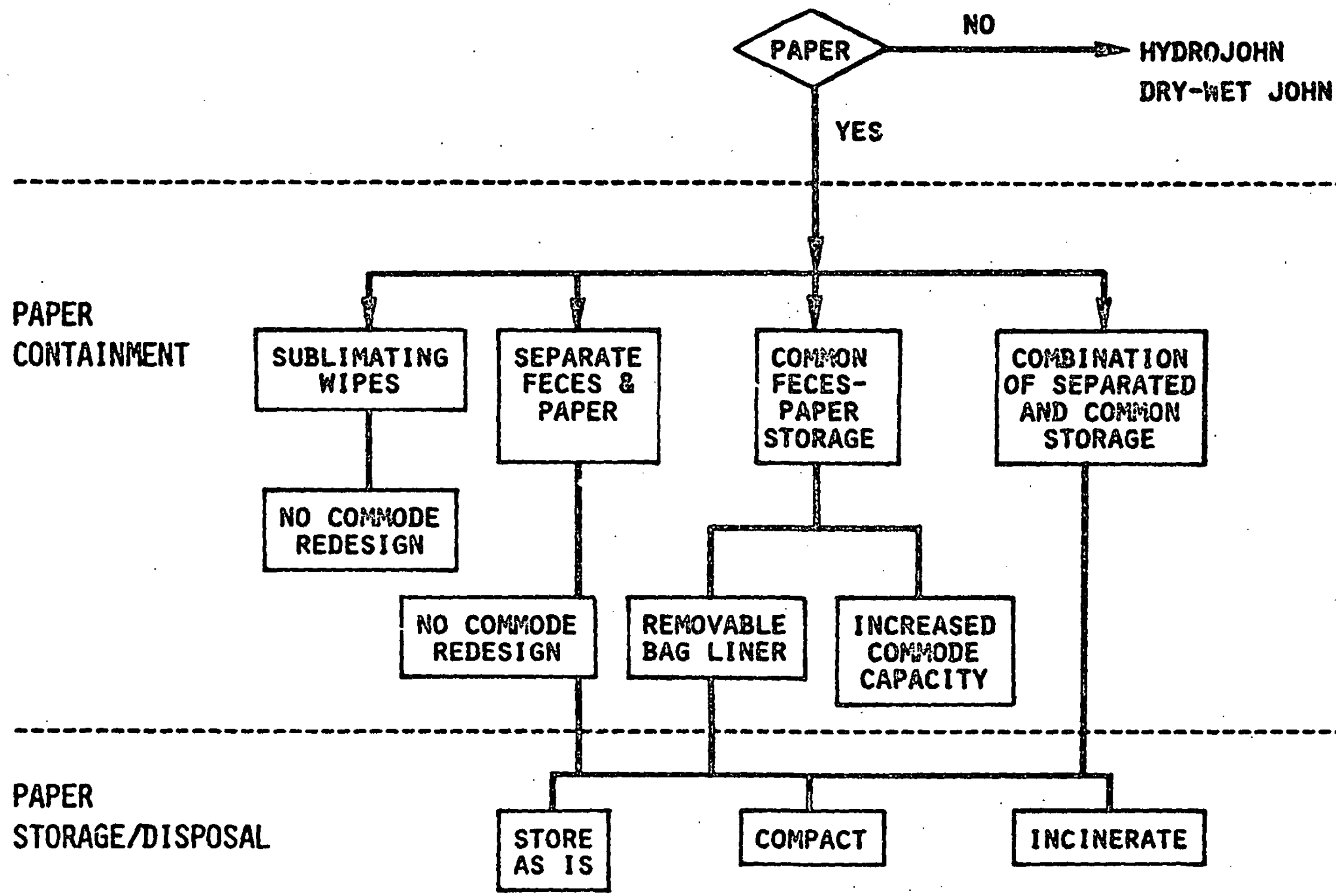
- sublimating wipes
- separate containment of feces and wipes
- common containment of feces and wipes
- a combination of separated and common containment of feces and wipes

and for storage and potential volume reduction:

- compaction
- incineration
- remain as is

and these alternatives formed the basis for selection of the alternative Improved WCS Concepts.

RESULTS OF MID-TERM REVIEW



LESSONS LEARNED FROM PAST EXPERIENCE

This chart identifies Improved WCS critical issues learned from experience gathered by General Electric Space Systems Division from fourteen flights and over 400 man-days usage of the current Waste Collection Subsystem. The variability in user characteristics and design drivers (solid waste volume), the design refinements and maturation based upon data gathered from in-flight experience, simplicity, the inability to demonstrate zero-g performance of the system prior to actual in-flight usage, and the strong need for extensive man/machine considerations in all system design areas are critical to an Improved WCS Design Concept definition.

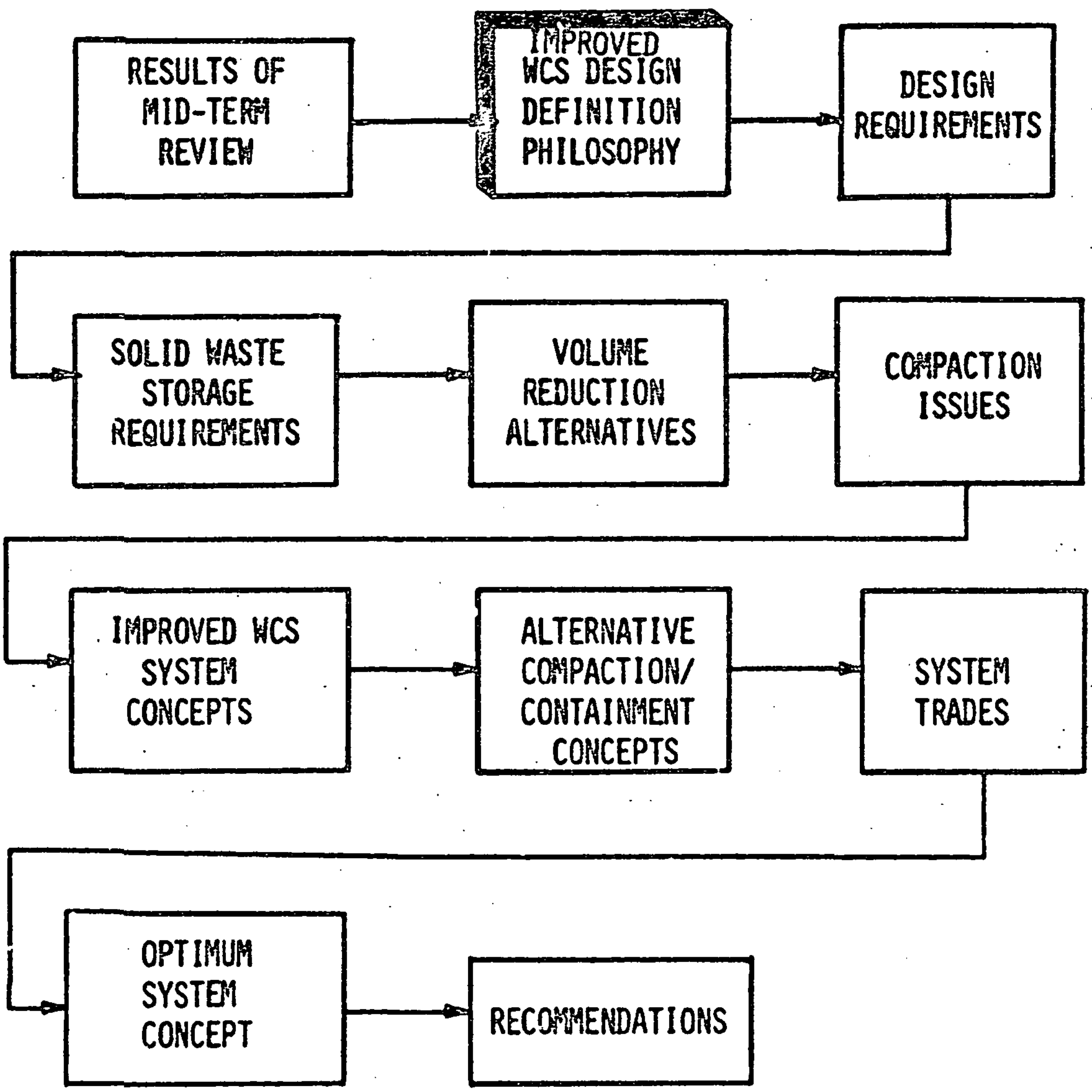
LESSONS LEARNED FROM PAST EXPERIENCE

- SOLID WASTE STORAGE VOLUME NEEDS CRITICAL
- SYSTEM SERVICEABILITY MUST RECEIVE EARLY DESIGN ATTENTION
- HABITABILITY FEATURES; E.G., NOISE AND EASE OF OPERATION, MUST BE PART OF THE SYSTEM DESIGN
- REFINEMENTS RESULTANT FROM IN-FLIGHT EXPERIENCE MAY BE NECESSARY TO OPTIMIZE SYSTEM
- SHORT TERM ZERO "G" TESTS ARE INSUFFICIENT FOR SYSTEM EVALUATION REQUIRING LONG TERM CREW INVOLVEMENT
- SIMPLICITY AND RELIABILITY MAJOR DESIGN FACTORS
- SYSTEM MUST BE ABLE TO ACCOMODATE WIDELY VARIANT DESIGN DRIVERS; E.G., URINE AND FECAL WIPES
- USER PREFERENCES ARE WIDELY VARIANT, BUT A MAJOR DESIGN CONSIDERATION
- SATISFACTORY AIR FLOW THROUGHOUT MISSION LIFE MAJOR DESIGN CONSIDERATION
- BACTERIAL AND ODOR CONTROL OVER MISSION LIFE MAJOR DESIGN CONSIDERATION

IMPROVED WCS DESIGN DEFINITION PHILOSOPHY

The following section establishes the Improved WCS Design definition philosophy.

FINAL PRESENTATION FLOW



IMPROVED WCS CONCEPT DESIGN DEFINITION PHILOSOPHY

The philosophy used in evolving an Improved WCS Concept is presented in this chart.

In that the current WCS represents a mature design, and based upon lessons learned from past experience, it was decided to minimize design risk and revisiting of past experiences by utilizing the current urine collection and containment methods, and retaining flight mature solid waste system elements and concepts, while eliminating the design deficiency in the current system regarding solid waste capacity, and incorporating the requirement to contain urine wipes within the WCS.

Additionally, as design goals, enhancement of in-flight serviceability of degradable elements and post-flight servicing of the WCS were established.

As part of the concept design definition philosophy, detailed design modifications (i.e., electrical, urine filtration) were considered by Eagle Engineering and are discussed in Appendix D, although not an integral part of the concept definition.

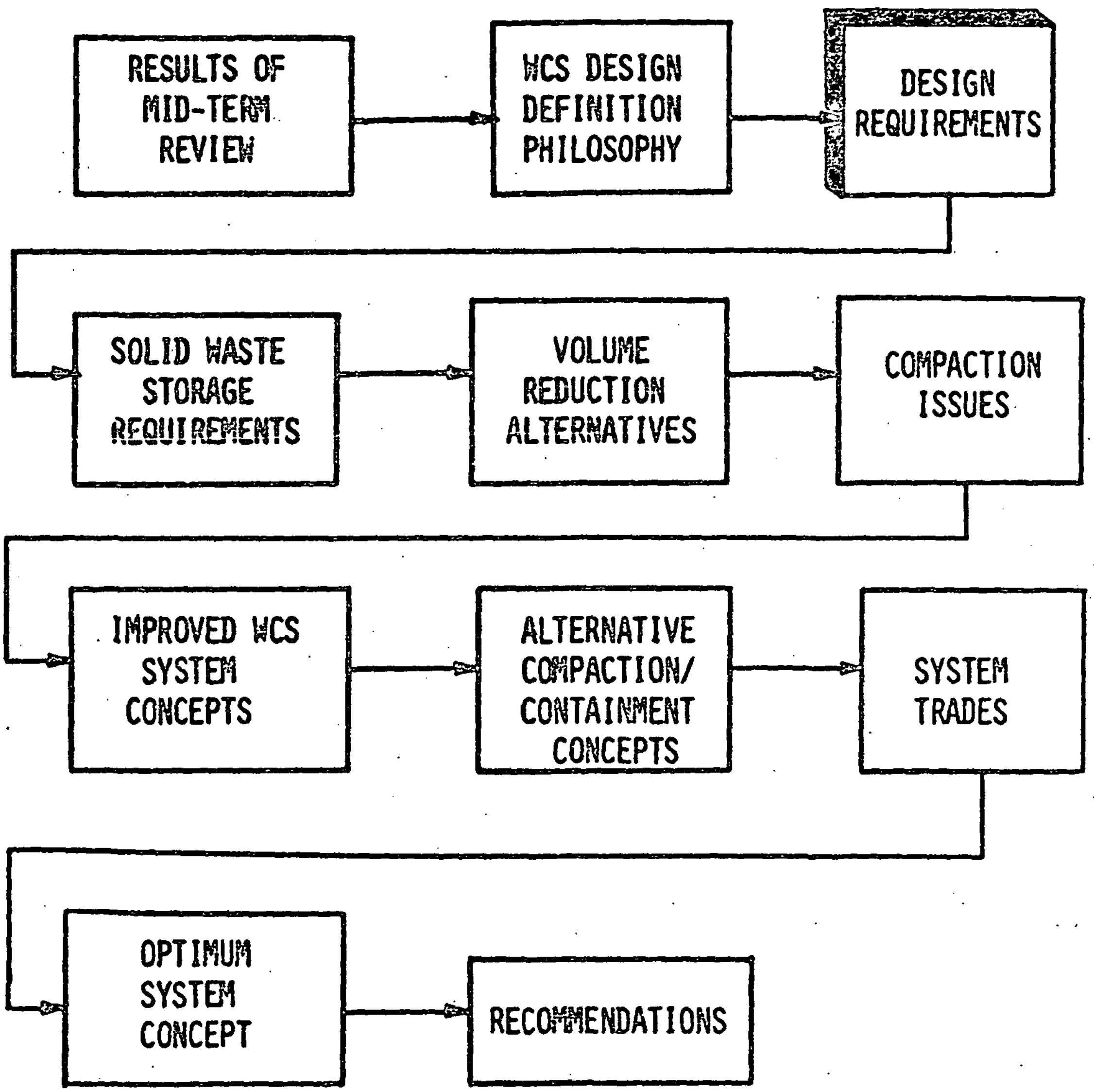
IMPROVED WCS CONCEPT DESIGN DEFINITION PHILOSOPHY

- CURRENT SYSTEM OPERATES SATISFACTORILY.
  - RETAIN CURRENT URINE COLLECTION AND CONTAINMENT METHODS.
  - RETAIN FLIGHT MATURE SOLID WASTE SYSTEM ELEMENTS AND CONCEPTS.
- ELIMINATE DESIGN LIMITATIONS.
  - LIMITED STORAGE CAPABILITY
- SATISFY NEW REQUIREMENTS
  - ALL WCS ASSOCIATED WASTE ELEMENTS REMAIN WITHIN WCS COMPARTMENT.
- ENHANCE IN-FLIGHT SERVICEABILITY OF DEGRADABLE SYSTEM ELEMENTS.
- ENHANCE POST FLIGHT SERVICEABILITY OF WCS.
- MINIMIZE EXPENDABLES CONSUMPTION.
- DETAILED DESIGN MODS (I.E. ELECTRICAL, URINE FILTRATION) SHOULD BE ADDRESSED IN A DETAILED DESIGN STUDY.

DESIGN REQUIREMENTS

The following section presents the Improved WCS design requirements.

FINAL PRESENTATION FLOW



PRIMARY DESIGN REQUIREMENTS

The four primary design requirements are presented in this chart.

An additional requirement over those imposed on the current WCS design is to contain urine wipes within the WCS.

Also, significant enhancement of the WCS system serviceability was specified.

PRIMARY DESIGN REQUIREMENTS

- SEPARATE WASTES FROM CREW MEMBERS:
  - EFFECTIVELY.
  - HYGIENICALLY.
- STORE THESE WASTES IN A SAFE, ODORLESS FORM WITHIN THE WCS COMPARTMENT.
- PROVIDE 210 MAN-DAYS CAPABILITY.
- SIGNIFICANTLY ENHANCE SYSTEM SERVICEABILITY.

SOW GENERAL DESIGN REQUIREMENTS

The general design requirements as presented in the Statement of Work of this contract are presented in this chart.

Major impacts on the study were the requirements to retrofit the Improved WCS within the current system compartment and to minimize crew interface with the wastes.

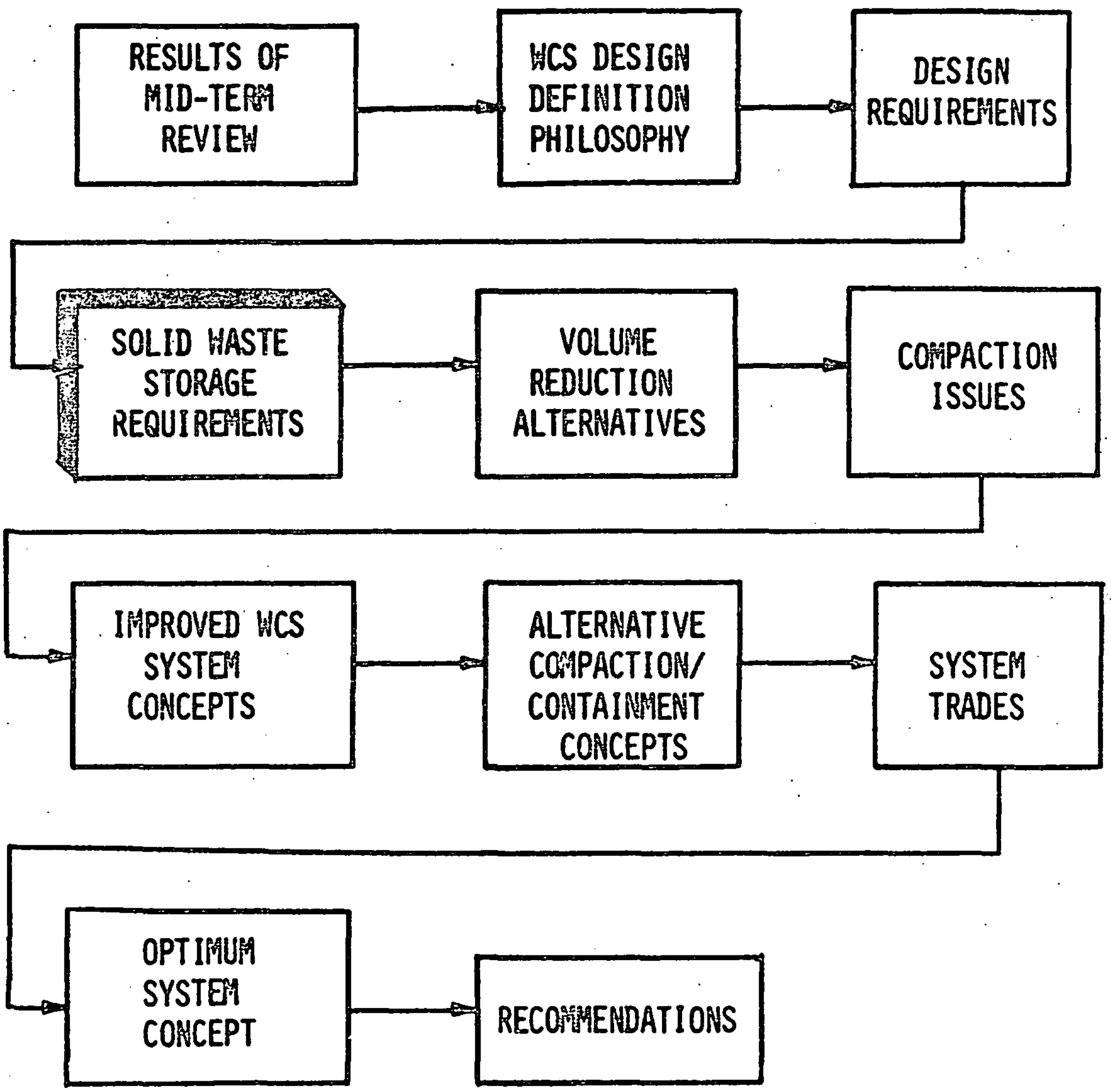
SOW GENERAL DESIGN REQUIREMENTS

- USABLE BY BOTH MALE AND FEMALE CREWMEMBERS.
- INDIVIDUALIZED URINE COLLECTION INTERFACE.
- EFFECTIVE, EFFICIENT STOOL SEPARATION.
- LAUNCH SITE MAINTAINABLE/SERVICEABLE.
- SIMPLE TO USE.
- MINIMAL TRAINING REQUIREMENTS.
- MINIMAL NOISE.
- RETROFITABLE WITHIN CURRENT SYSTEM COMPARTMENT.
- RELIABLE.
- MINIMAL CREW INTERFACE WITH WASTES.
- ADEQUATE BODY STABILIZATION.
- BACTERIA AND ODOR CONTROL.

SOLID WASTE STORAGE REQUIREMENTS

The following section presents the solid waste storage requirements.

FINAL PRESENTATION FLOW



SOLID WASTE STORAGE REQUIREMENTS-ASSUMPTIONS ON AVERAGE USAGE

Average usage requirements for an Improved WCS are presented in this chart. These usages were assumed to establish volume requirements for an Improved WCS.

Significantly, examination of usage data and a review of astronaut comments emphasized a large variability in wipes usage rates, and indicated the necessity to conceptualize a WCS concept which did not base its capacity on specified usage rates.

This data stressed the desirability of a variable capacity system.

SOLID WASTE STORAGE REQUIREMENTS

ASSUMPTIONS ON AVERAGE USAGE

- WIPES USAGE

  - DEFECATION REQUIREMENTS:

    5 WIPES/DEFECATION
    1 DEFECATION/MAN-DAY

  - URINATION CLEANSING REQUIREMENTS:

    2 WIPES/URINATION
    6 URINATIONS/MAN-DAY

  - 210 MAN-DAY WIPES REQUIREMENTS:

    DEFECATION: 5 x 210 = 1050 WIPES
    URINATION: 2 x 6 x 210 = 2520 WIPES

TOTAL WIPES USAGE: 3570

- PAST USAGE DATA AND ASTRONAUT COMMENTS EMPHASIZE LARGE VARIABILITY IN WIPES USAGE RATES.

ASSUMPTIONS ON AVERAGE USAGE (CONTINUED)

This chart presents data on the fecal production for a 210 man-day Shuttle mission.

The fecal production during a 210 man-day mission is determinable based on knowledge of crew food consumption.

Significant variability in this quantity should not be expected.

It should be noted that the 1 ft^3 volume production is based upon 100% packing efficiency of fecal material, a condition theoretically achievable if the fecal material is compacted or otherwise reduced to eliminate spaces, etc. in the collection of undisturbed fecal matter.

Testing should be performed prior to the finalization of tank sizes to determine typical feces packing efficiencies.

ASSUMPTIONS ON AVERAGE USAGE (CONTINUED)

- FECAL PRODUCTION
  - ASSUME FECES HAS DENSITY OF WATER.
  - AVERAGE PRODUCTION = 0.3 LBS/MAN-DAY
    = 0.005 FT^3/MAN-DAY
  - 210 MAN-DAY FECAL PRODUCTION = 1 FT^3

VOLUME REQUIREMENTS

Solid waste volume requirements, which include feces, fecal wipes, and urine wipes, are presented in this chart.

These wipes volume requirements were established based upon rudimentary unused wipes crumpling tests conducted at General Electric Company - Space Systems Division at Valley Forge, Pennsylvania. The tests were conducted with the wipes currently in use on the Shuttle Orbiter. Wipes usage rates as previously presented were used. It should be noted that the wipes volume requirements are conservative, as they assume no packing, and the fecal volume requirement is optimistic as it assumes 100% packing efficiency, at the very best achievable with compacted feces.

On these bases, the total volume requirements approximate 50 ft^3.

As the current WCS has a capacity of approximately 2.7 ft^3, the limitation of the current tank to accommodate all solid waste materials without incorporating some volume reduction methodology is established.

Note that the inclusion of the urine wipes in the Improved WCS, a system capability not currently incorporated in the WCS, significantly impacts the solid waste volume storage requirements of the WCS. However, even without this requirement, the ability of the WCS to accommodate the fecal matter and fecal wipes is in question.

VOLUME REQUIREMENTS

- BASED ON TESTS MADE WITH WIPES CURRENTLY BEING USED.
- RUDIMENTARY TESTS OF CRUMPLING WIPES SHOW:
  - CRUMPLED PER WIPES VOLUME = 23.5 IN^3 = .0135 FT^3
- FECAL WIPES VOLUME REQUIREMENT = 1050 x .0135 = 14.2 FT^3
- URINE WIPES VOLUME REQUIREMENT = 2520 x .0135 = 34 FT^3
- REQUIREMENTS CONSERVATIVE AS NO PACKING FACTOR INCLUDED.
- FECAL VOLUME REQUIREMENTS = 1 FT^3
- FECAL VOLUME REQUIREMENTS ASSUMES 100% PACKING EFFICIENCY.

VOLUME REQUIREMENTS (CONTINUED)

In that the Improved WCS must be retrofitable within the current WCS compartment, two important conclusions can be drawn:

(1) feces represent a small fraction of the total solid waste volume generated as a result of the defecation and urination processes; and

(2) a paper volume reduction methodology must be established.

VOLUME REQUIREMENTS (CONTINUED)

CONCLUSIONS

- FECAL MATTER REPRESENTS SMALL FRACTION OF SOLID WASTE.
- PAPER VOLUME MUST BE REDUCED TO PERMIT VIABLE WCS CONCEPTS CONTAINABLE IN WCS COMPARTMENT.

VOLUME REDUCTION ALTERNATIVES

This section discusses volume reduction alternatives, trades the various options, and concludes with a recommended method for reducing paper volume.

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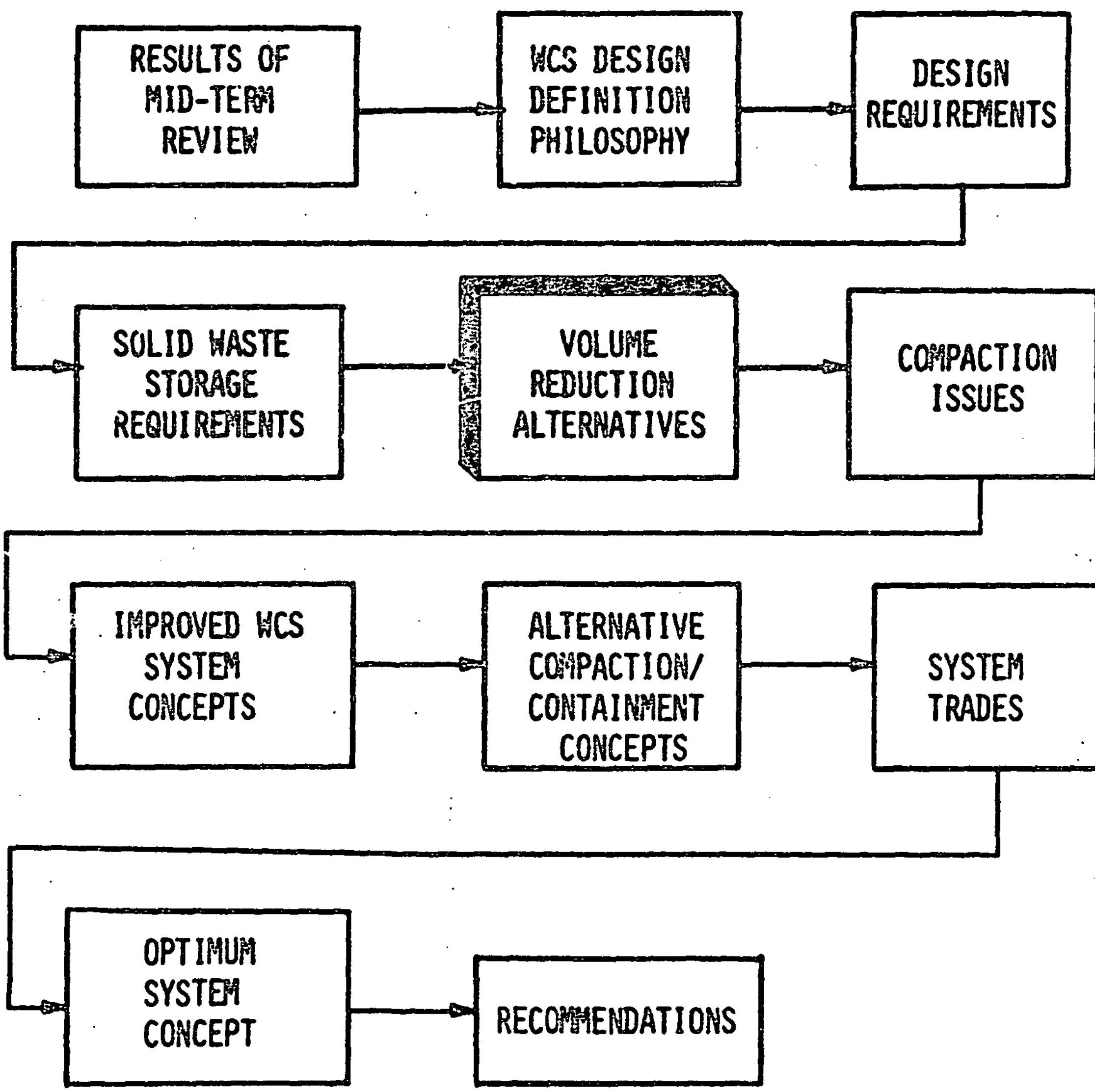


PAPER VOLUME REDUCTION ALTERNATIVES

Three methods were considered for reducing the volume of the paper generated during WCS usage over a 210 man-day mission:

- o sublimating wipes
- o compaction
- o incineration

Incineration was eliminated for Shuttle applications for the following reasons:

(1) fire hazards to the Shuttle

(2) contamination of other Shuttle elements from by-products of the incineration process

(3) power consumption

A discussion of the two remaining volume reduction methods follows.

PAPER VOLUME REDUCTION ALTERNATIVES

- SUBLIMATING WIPES
- COMPACTION
- INCINERATION CONSIDERED TOO RISKY FOR SHUTTLE APPLICATIONS

SUBLIMATING WIPES

This chart summarizes the results of an investigation into the usage of a new wipes material - specifically, one that sublimates - in place of the current ones. A sublimating wipe would eliminate the paper volume problem, and permit usage of the current system.

Paper industry research indicated the conflict between the structural requirements for a wipe which both sublimates and maintains structural integrity through the wipe process.

Research into ultra-violet decomposition of synthetic fibers appears promising. Inclusion of this approach in the Improved WCS is not recommended, however, due to the premature state of the technology, the significant complications to the WCS, and the potential impacts of the sublimation/decomposition processes and by-products on other Shuttle orbiter subsystems.

SUBLIMATING WIPES

- INVESTIGATED PAPER INDUSTRY RESEARCH RELATED TO WIPE MATERIAL DEVELOPMENT.
- WIPE STRENGTH $\propto$ F (POLYMER CHAIN LENGTH)
- SUBLIMATION $\propto F\left(\dfrac{1}{\text{POLYMER CHAIN LENGTH}}\right)$

CONCLUSION:

- CONFLICTING MATERIAL STRUCTURAL REQUIREMENTS INDICATE DEVELOPMENT OF SUBLIMATING WIPES UNREALISTIC
- CURRENT RESEARCH IN ULTRAVIOLET DECOMPOSITION OF SYNTHETIC FIBERS PROMISING
- INCLUSION IN WCS NOT RECOMMENDED.
  - SIGNIFICANTLY COMPLICATES SYSTEM
  - REQUIRES EXTENSIVE INVESTIGATION INTO OUTGASSING AND CONTAMINATION IMPACT ON OTHER SHUTTLE ORBITER SUBSYSTEMS.

COMPACTION

This chart demonstrates that compaction is a viable methodology for paper volume reduction.

Compacted wipes volume requirements based on the usage rates previously presented are computed. Rudimentary tests at the General Electric Company, Space Systems Division, demonstrated that the wipes can easily be compacted to at least their original volume (before use), and probably further.

Hence, a compacted wipes volume of 1.1 ft^3 is required for 210 man-days of Improved WCS use.

Note that the large variability in usage rates indicates the necessity of a concept development which is volume independent; e.g., a variable capacity system.

COMPACTION

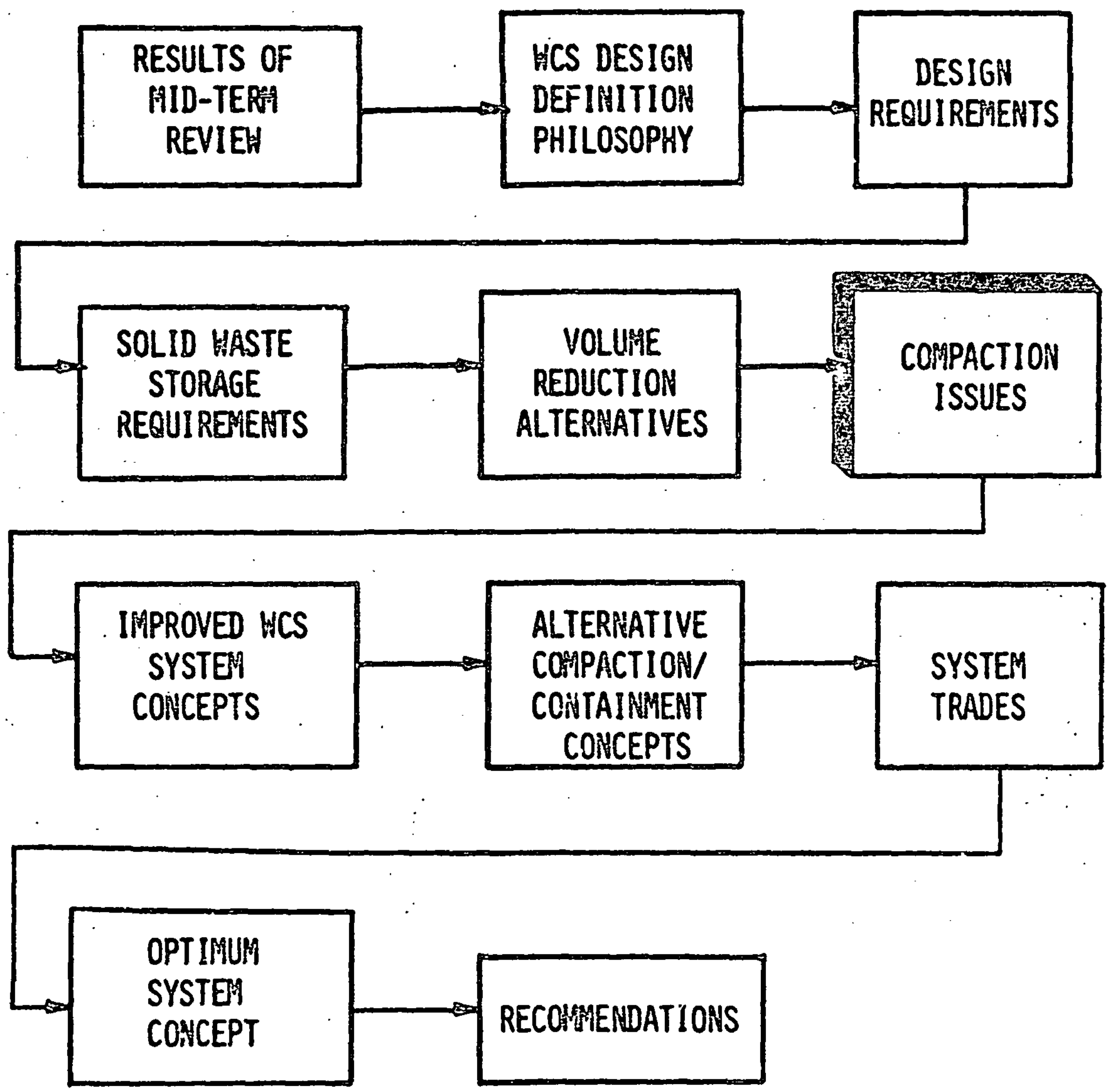
- WIPES CAN BE COMPACTED TO ORIGINAL VOLUME.
  - DEMONSTRATED IN RUDIMENTARY TESTING AT GENERAL ELECTRIC SPACE DIVISION.
- PER WIPE COMPACTED VOLUME = 0.53 IN^3
- TYPICAL 210 MAN-DAY REQUIREMENTS:
  - FECAL WIPES = 1050 X 0.53 = 0.32 FT^3
  - URINATION WIPES = 2520 X 0.53 = 0.77 FT^3

  TOTAL 1.09 FT^3
- VOLUME REQUIREMENTS BASED ON TYPICAL USAGE, BUT PAST UTILIZATION DATA AND ASTRONAUT COMMENTS EMPHASIZES LARGE VARIABILITY IN WIPES USAGE RATES.
- COMPACTION REPRESENTS VIABLE METHODOLOGY FOR PAPER VOLUME REDUCTION.

COMPACTION ISSUES

The next section discusses issues related to the compaction process and draws conclusions regarding their impact on the Improved WCS concept development.

FINAL PRESENTATION FLOW



SYSTEM IMPACTS OF COMPACTION

Two potential system impacts of compaction are identified in this chart.

- o reduction in air flow due to the density of compacted materials
- o performance degradation in impacted porous elements when fecal material is compacted.

These limitations, coupled with the large variability expected in wipes usage, demand that:

- o in-flight serviceability of potentially impacted system elements must be provided.

This may be implemented by using the flight demonstrated bag liner concept in the Improved WCS, providing for in-flight changeability of a bag liner if either the capacity of the bag is saturated, or extended air flow degradation causes impaired system performance.

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SYSTEM IMPACTS OF COMPACTION

- COMPACTION RESULTS IN EXTREMELY DENSE WASTE MATERIALS WITH POSSIBLE IMPACT ON SYSTEM AIR FLOW.
- COMPACTION OF FECES MAY IMPACT PERFORMANCE OF FILTRATION AND CONTAINMENT ELEMENTS.

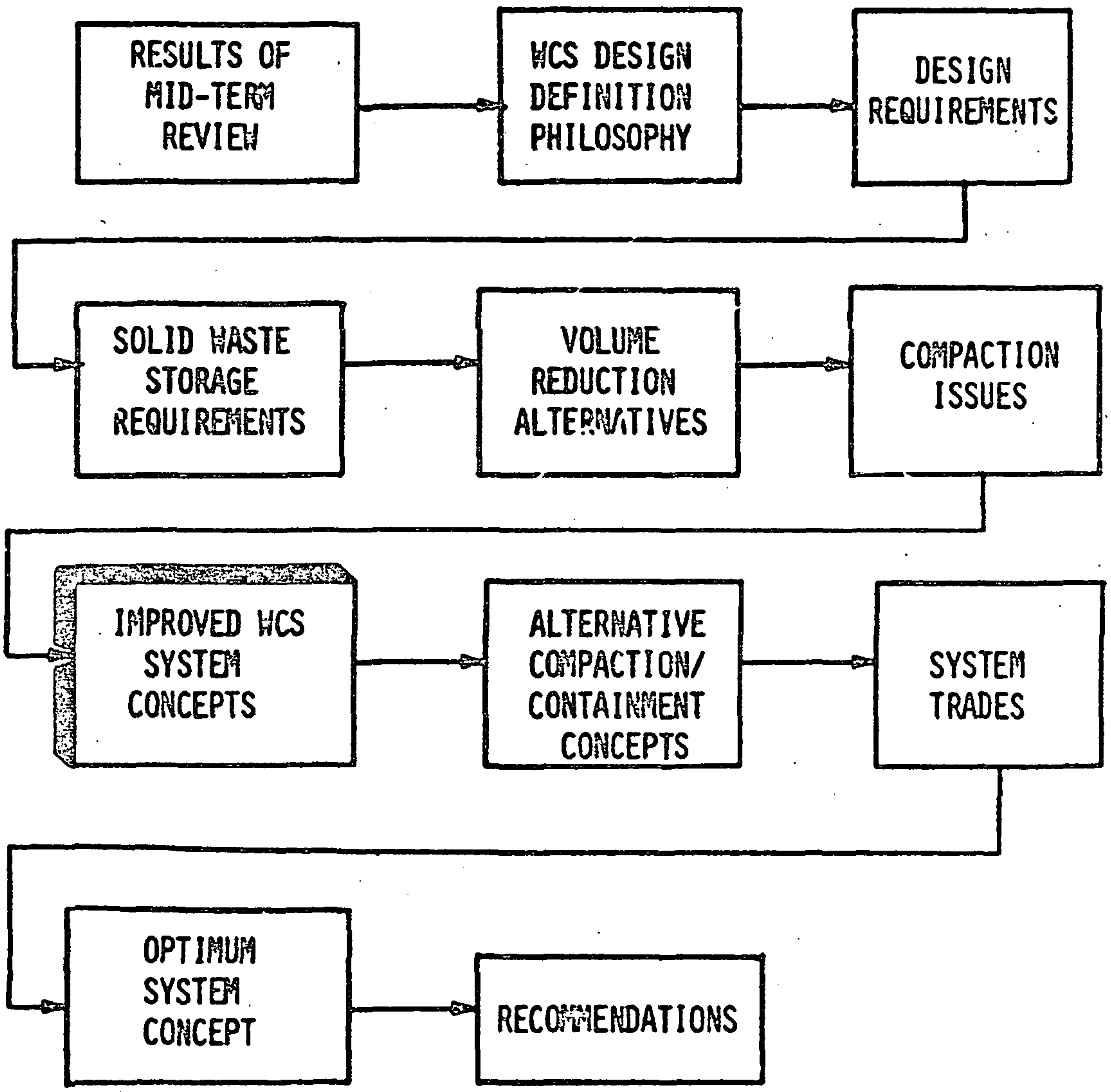
CONCLUSION

IN-FLIGHT SERVICEABILITY OF POTENTIALLY IMPACTED ELEMENTS MUST BE PROVIDED.

IMPROVED WCS SYSTEM CONCEPT

The following section presents the Improved WCS system concept; those elements of the Improved concept to be optimized are identified.

FINAL PRESENTATION FLOW



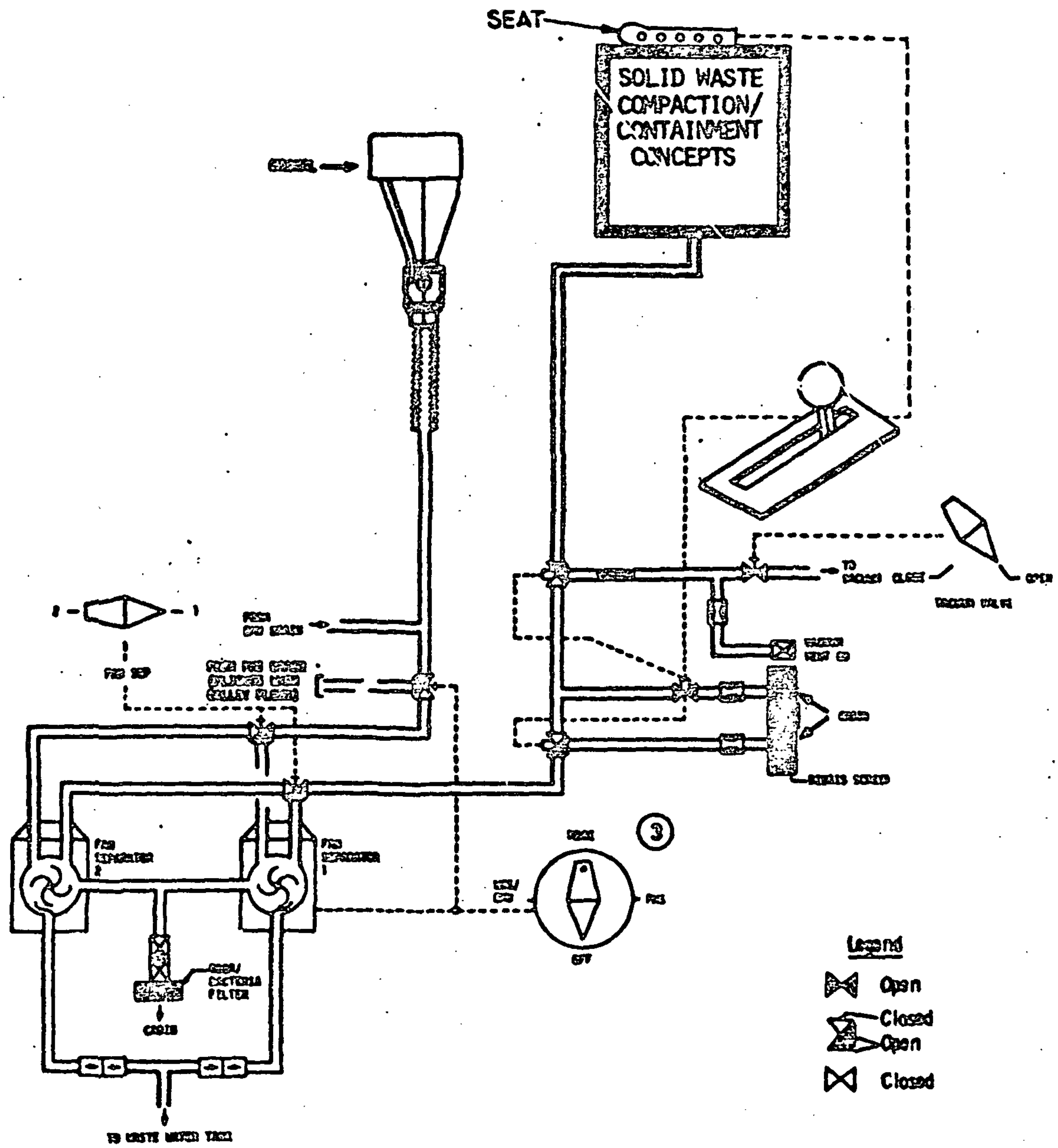
IMPROVED WCS SYSTEM CONCEPT

The generalized Improved WCS System Concept is presented on the facing page. As is shown, the Improved WCS uses flight-pr elements of the current system.

Concept optimization will be achieved by establishing a con ept for containment and compaction of the solid wastes.

Valving and controls are representative, but dependent on the details of the final configuration.

IMPROVED WCS SYSTEM CONCEPT



IMPROVED WCS SYSTEM CONCEPT

This chart summarizes the General Electric design philosophy and goals of the Improved WCS.

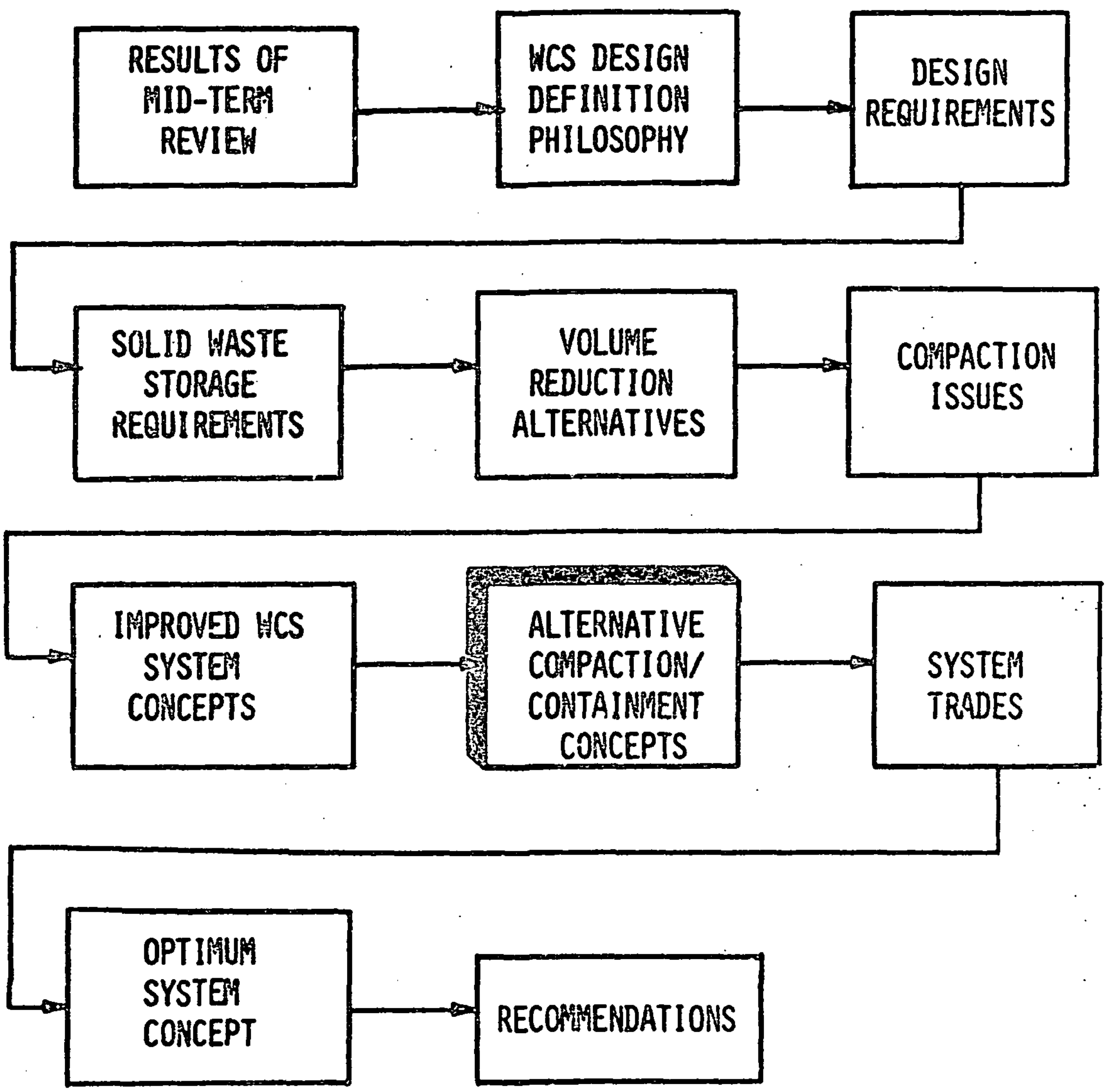
IMPROVED WCS SYSTEM CONCEPT

- UTILIZES FLIGHT-PROVEN CONCEPTS AND TECHNOLOGIES.
- TAKES ADVANTAGE OF LESSONS LEARNED FROM EXTENSIVE PAST IN-FLIGHT EXPERIENCES.
- WILL RESOLVE EXISTING DESIGN LIMITATIONS.
- WILL PROVIDE IN-FLIGHT SERVICEABILITY OF DEGRADABLE SYSTEM ELEMENTS.

ALTERNATIVE COMPACTION/CONTAINMENT CONCEPTS

The following section presents the alternative compaction/containment concepts. These represent variations in the design and operation of the Improved WCS.

FINAL PRESENTATION FLOW



ALTERNATIVE COMPACTION/CONTAINMENT CONCEPTS

This chart identifies the representations developed for the three compaction/containment alternatives presented in the summarization of the Midterm Review.

The single tank compactor concept is the representation for common storage of feces and all wipes; the dual tank compactor concept is the representation for a combination of separated and common storage, and the three tank compactor concept is a representative implementation of the separated storage of feces and wipes.

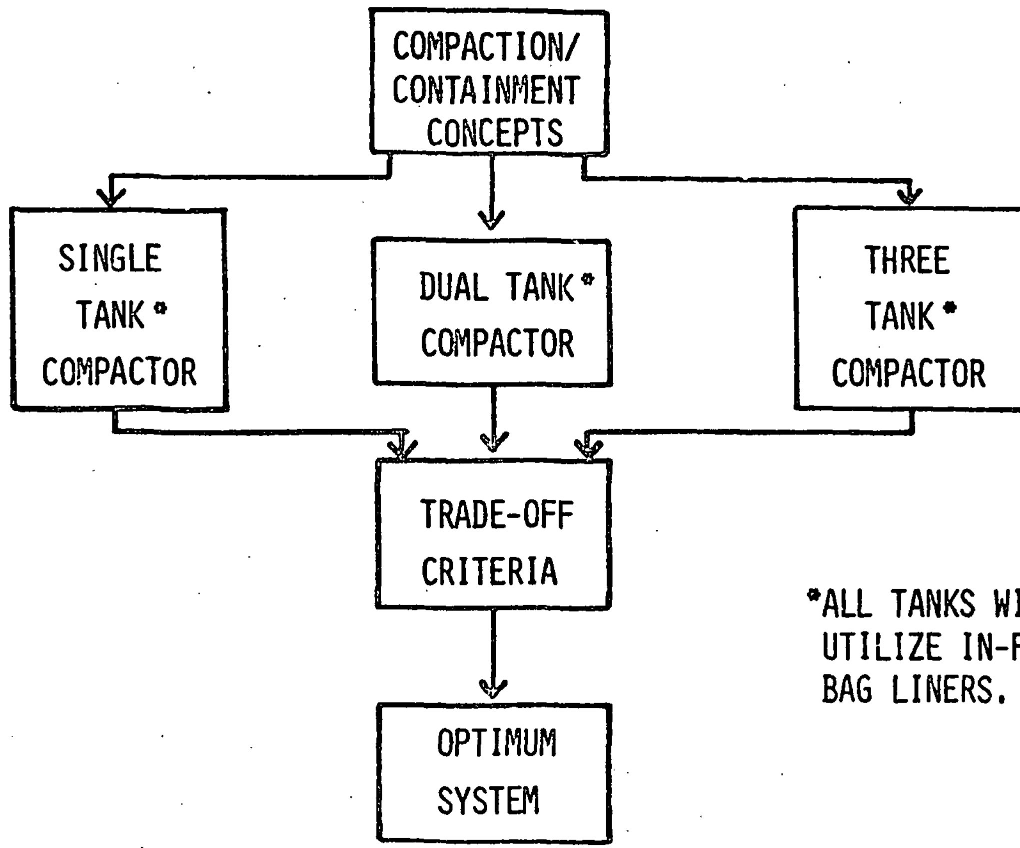
The three alternatives are described in the following pages and then traded off to define the optimum system concept.

Significant to all concepts is the utilization of all split tanks with in-flight replaceable bag liners to permit in-flight servicing of all containment vessels.

HOUSTON OPERATIONS

SPACE SYSTEMS DIVISION

ALTERNATIVE COMPACTION/CONTAINMENT CONCEPTS



*ALL TANKS WILL BE SPLIT AND UTILIZE IN-FLIGHT REPLACEABLE BAG LINERS.

SINGLE TANK COMPACTOR SYSTEM CONCEPT

The single tank compactor system concept is a representative implementation for common storage of feces and all wipes.

In this configuration, feces and wipes are deposited in the same tank and all material is compacted to reduce volume.

SINGLE TANK COMPACTOR SYSTEM CONCEPT

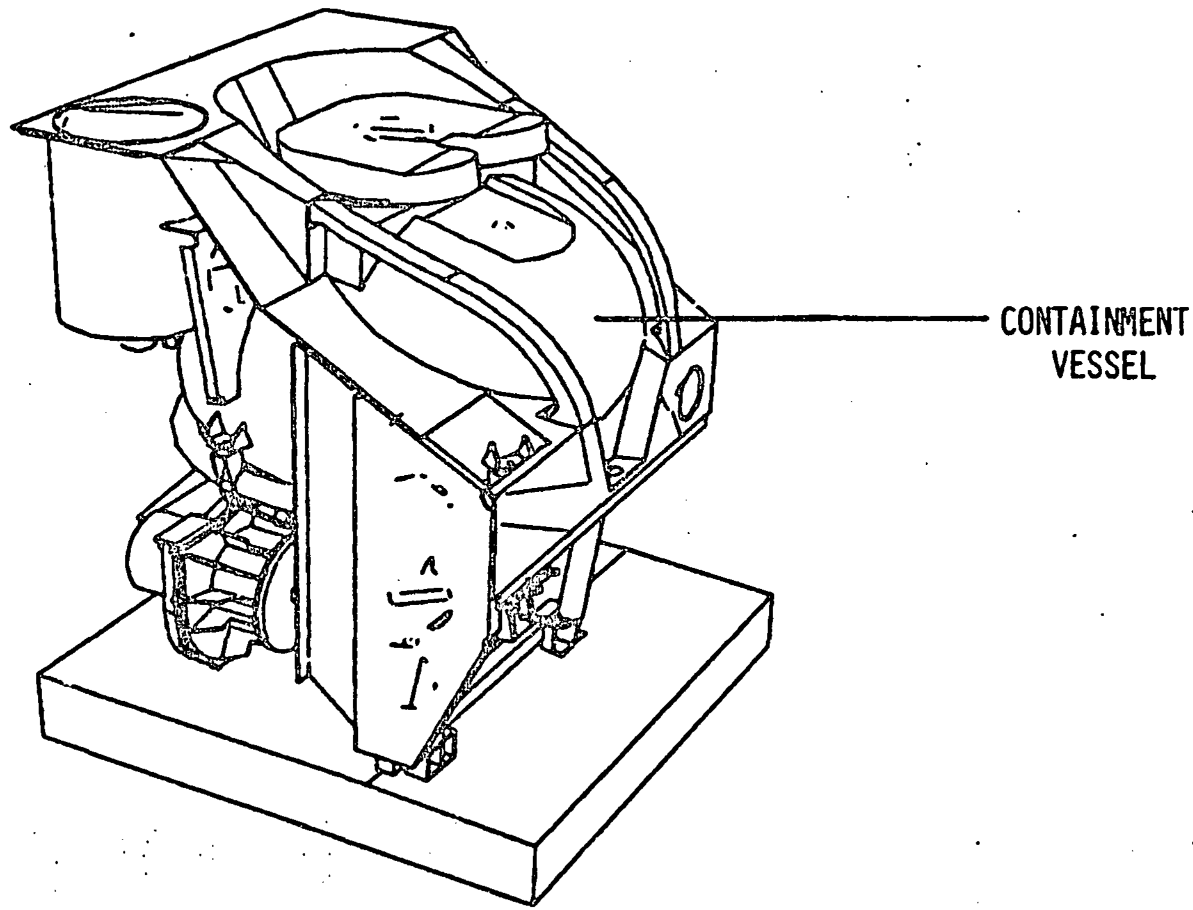
- SINGLE SOLID WASTE CONTAINMENT VESSEL

  - FECES AND ALL WIPES DEPOSITED IN SAME TANK WITH INTERNAL COMPACTOR.

TYPICAL SINGLE TANK COMPACTOR SYSTEM CONCEPT CONFIGURATION

This chart presents a Computer Aided Engineering (GEOMOD) representation of the Single Tank Compactor Concept, and illustrates the representative packaging of this concept within the current WCS housing. Significantly, all wipes-feces and urine are deposited within the single tank (sized at 3.23 ft^3) and the tank contents are compacted and vacuum dried. The tank must be opened for deposition of feces and fecal wipes, and for depositing urine wipes.

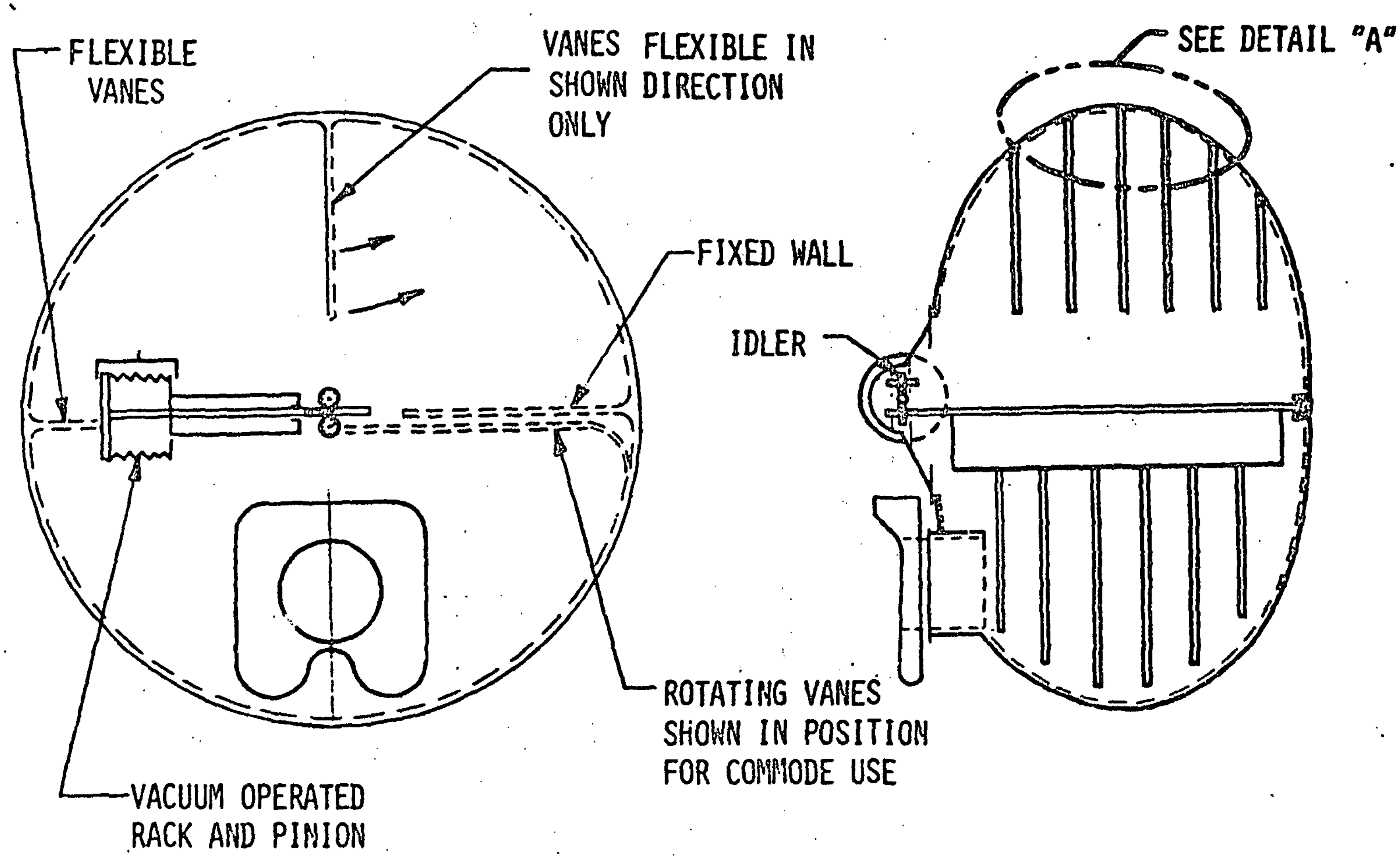
TYPICAL SINGLE TANK COMPACTOR SYSTEM CONCEPT CONFIGURATION



ROTARY VANE COMPACTOR

The illustration on the facing page shows a representative configuration of a rotary vane compactor that may be used in the fecal storage tanks. Upon completion of the defecation and the cleaning processes, the tank is closed and evacuated. The evacuation of the tank causes the expansion of the bellows which drives a rack and pinion. The rack and pinion transfers the linear force from the bellows to a rotary force on the rotary vane axle. This causes the rotary vane to rotate clockwise, when seen from the top view. As it rotates clockwise, the vanes pick up any feces and wipes deposited in the tank and compacts it against the fixed wall. The vanes will remain in the compacted position until the tank is repressurized. When the tank is repressurized, the vanes rotate counterclockwise, as seen from a top view and pass through flexible vanes. The flexible vanes are positioned so as to remove any fecal matter or wipes from the rotating vanes. The rotating vanes are shown in position for commode use.

ROTARY VANE COMPACTOR



DETAIL "A" TANK/BAG LINER DETAIL

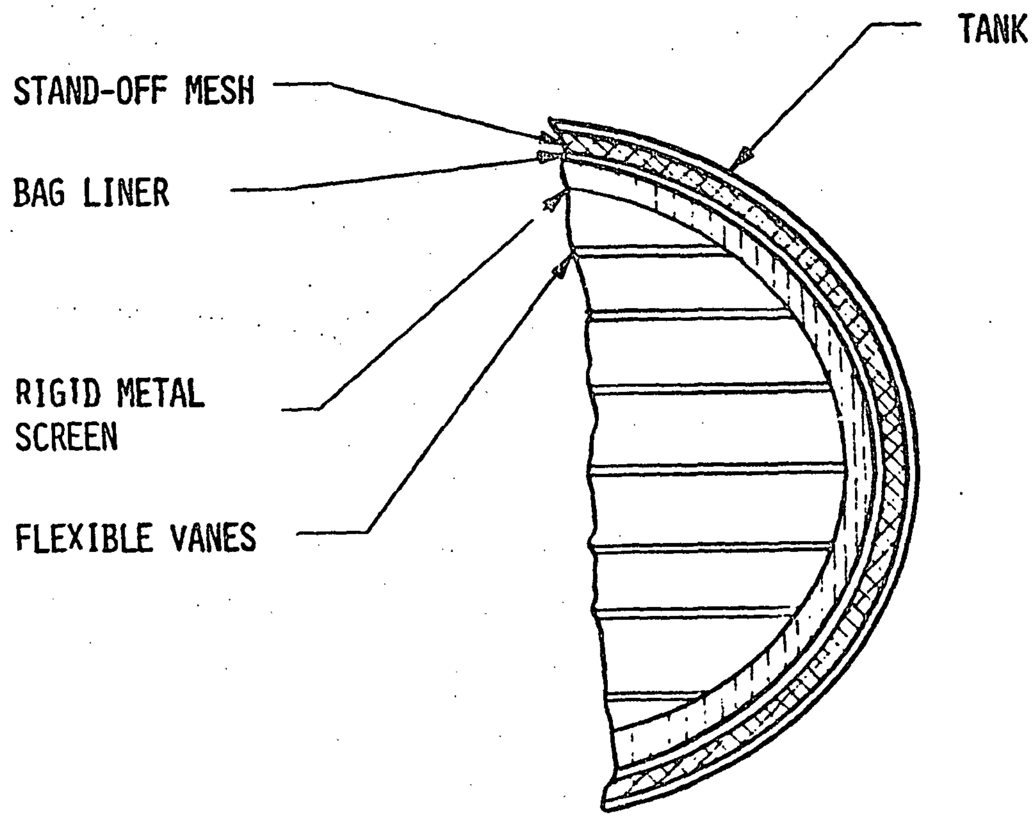
The illustration on the facing shows a tank/bag liner detail for the rotary vane compactor. Problems that may arise during the use of a rotary vane compactor are air flow degradation caused by clogging of the bag liner or a bag liner hole generation (caused by the rotating vanes. Clogging of the bag liner may be caused by the spreading of feces on the bag liner surface, somewhat similar to spreading mud on a household window screen, which could dramatically and quickly reduce air flow. Flexible vanes would generate holes at a "high" spot of the bag liner during their rotation. The detail of a representative rotary vane compactor on the facing page solves these issues. The stand-off mesh and metal screen provide a rigid structure and shape required for the compactor and the bag liner. The rigid metal screen is also the mounting surface for the flexible vanes and is more resistant to air flow degradation around the entire bag liner surface. The stand-off mesh also provides for good air flow. In-flight servicing of a tank with rotary vane compactor dictates that space must be dedicated to store the bags and rigid structures that contains the replacement bag liner and compactor. Also, space must be dedicated to store the bag liner structure that was replaced.

HOUSTON OPERATIONS

SPACE SYSTEMS DIVISION

DETAIL "A"

TANK/BAG LINER DETAIL



DUAL COMPACTOR SYSTEM CONCEPT

The dual compactor system concept is a representative implementation permitting separate urine wipes storage.

Feces and fecal wipes (both separation and cleansing) are deposited in the fecal waste containment vessel, with a compaction device internal to the bag liner within this vessel to reduce volume. This vessel has to be accessed only when the defecation process is performed.

Urine wipes are deposited into the urine wipes containment vessel. These wipes are similarly compacted to reduce volume, although the compaction device is not internal to the bag liner. This vessel is accessed when the cleansing process is performed subsequent to urination.

DUAL COMPACTOR SYSTEM CONCEPT

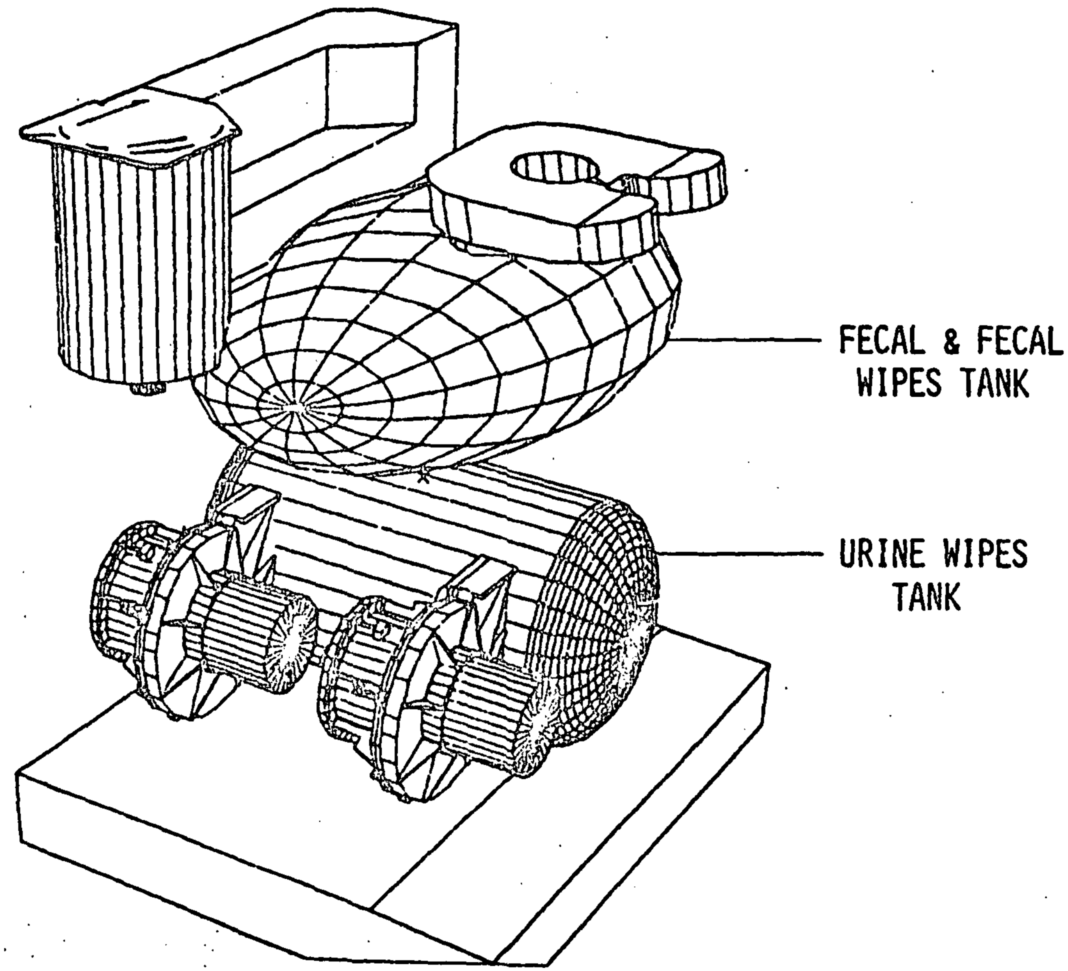
- TWO SOLID WASTE CONTAINMENT VESSELS.
  - FECES AND FECAL WIPES DEPOSITED INTO FECAL WASTE CONTAINMENT VESSEL WITH INTERNAL ROTARY VANE COMPACTOR.
  - URINE WIPES DEPOSITED INTO URINE WIPES CONTAINMENT VESSEL WITH INTERNAL PISTON COMPACTOR.

TYPICAL DUAL COMPACTOR SYSTEM CONCEPT CONFIGURATION

This figure presents a Computer Aided Engineering (GEOMOD) representation of the Dual Compactor System Concept, and illustrates a typical packaging of this concept within the current WCS housing.

Significantly, the feces and fecal wipes are deposited and compacted within the fecal wipes tank (sized at 1.75 ft^3), and the urine wipes are deposited and compacted within the urine wipes tank (sized at 1 ft^3). Vacuum drying of the contents of both tanks is provided. Tank access is as previously described.

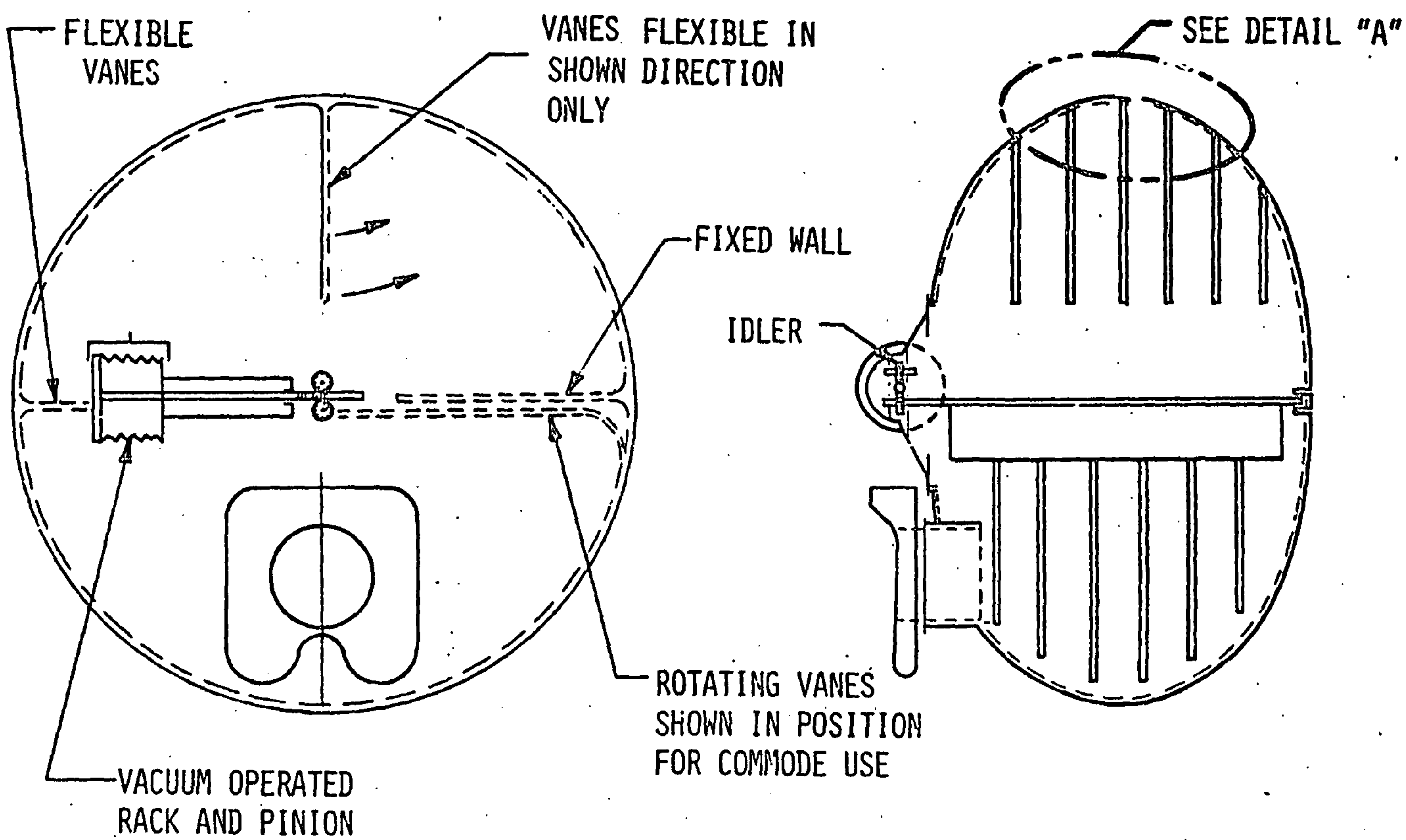
TYPICAL DUAL COMPACTOR SYSTEM CONCEPT CONFIGURATION



ROTARY VANE COMPACTOR

The illustration on the facing page shows a representative configuration of a rotary vane compactor that may be used in the fecal storage tanks. Upon completion of the defecation and the cleaning processes, the tank is closed and evacuated. The evacuation of the tank causes the expansion of the bellows which drives a rack and pinion. The rack and pinion transfers the linear force from the bellows to a rotary force on the rotary vane axle. This causes the rotary vane to rotate clockwise, when seen from the top view. As it rotates clockwise, the vanes pick up any feces and wipes deposited in the tank and compacts it against the fixed wall. The vanes will remain in the compacted position until the tank is repressurized. When the tank is repressurized, the vanes rotate counterclockwise, as seen from a top view and pass through flexible vanes. The flexible vanes are positioned so as to remove any fecal matter or wipes from the rotating vanes. The rotating vanes are shown in position for commode use.

ROTARY VANE COMPACTOR



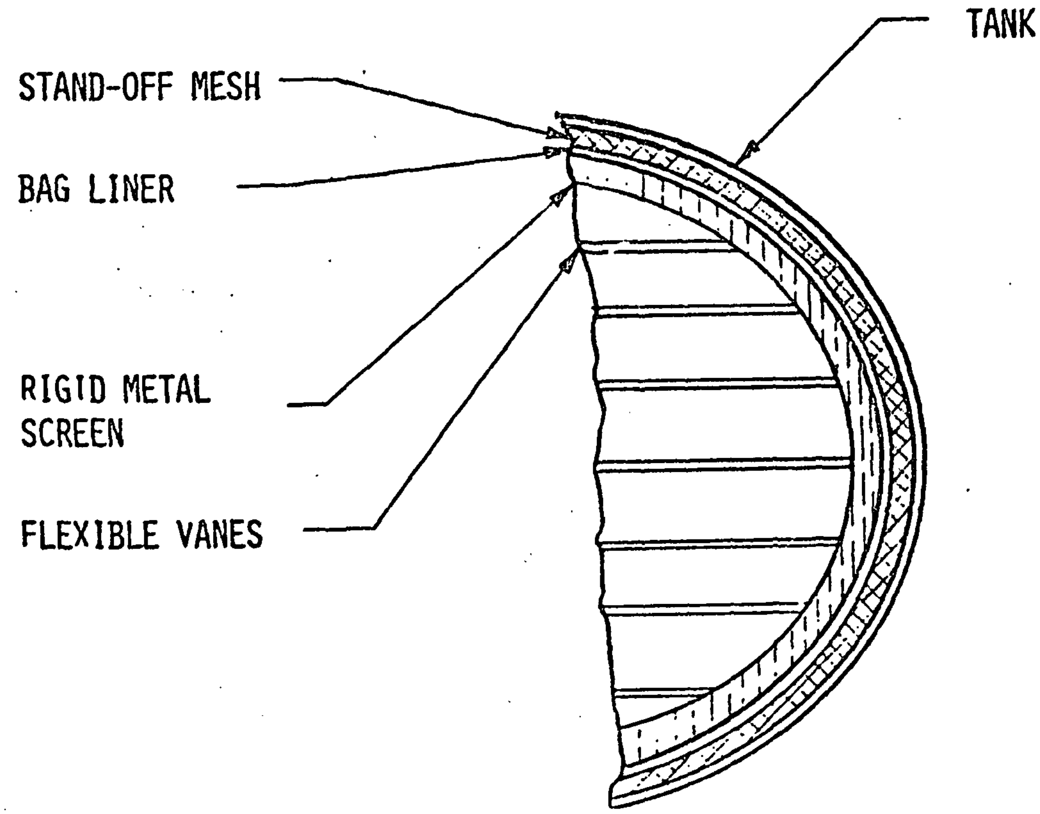
DETAIL "A" TANK/BAG LINER DETAIL

The illustration on the facing shows a tank/bag liner detail for the rotary vane compactor. Problems that may arise during the use of a rotary vane compactor are air flow degradation caused by clogging of the bag liner or a bag liner hole generation (caused by the rotating vanes. Clogging of the bag liner may be caused by the spreading of feces on the bag liner surface, somewhat similiar to spreading mud on a household window screen, which could dramatically and quickly reduce air flow. Flexible vanes could cause a hole at a "high" spot of the bag liner during their rotation. The detail of a representative rotary vane compactor on the facing page solves these issues. The stand-off mesh and metal screen provide a rigid structure and shape required for the compactor and the bag liner. The rigid metal screen is also the mounting surface for the flexible vanes and is more resistant to air flow degradation around the entire bag liner surface. The stand-off mesh also provides for good air flow. In-flight servicing of a tank with rotary vane compactor dictates that space must be dedicated to store the bags and rigid structures that contains the replacement bag liner and compactor. Also, space must be dedicated to store the bag liner structure that was replaced.

HOUSTON OPERATIONS

SPACE SYSTEMS DIVISION

DETAIL "A"
TANK/BAG LINER DETAIL

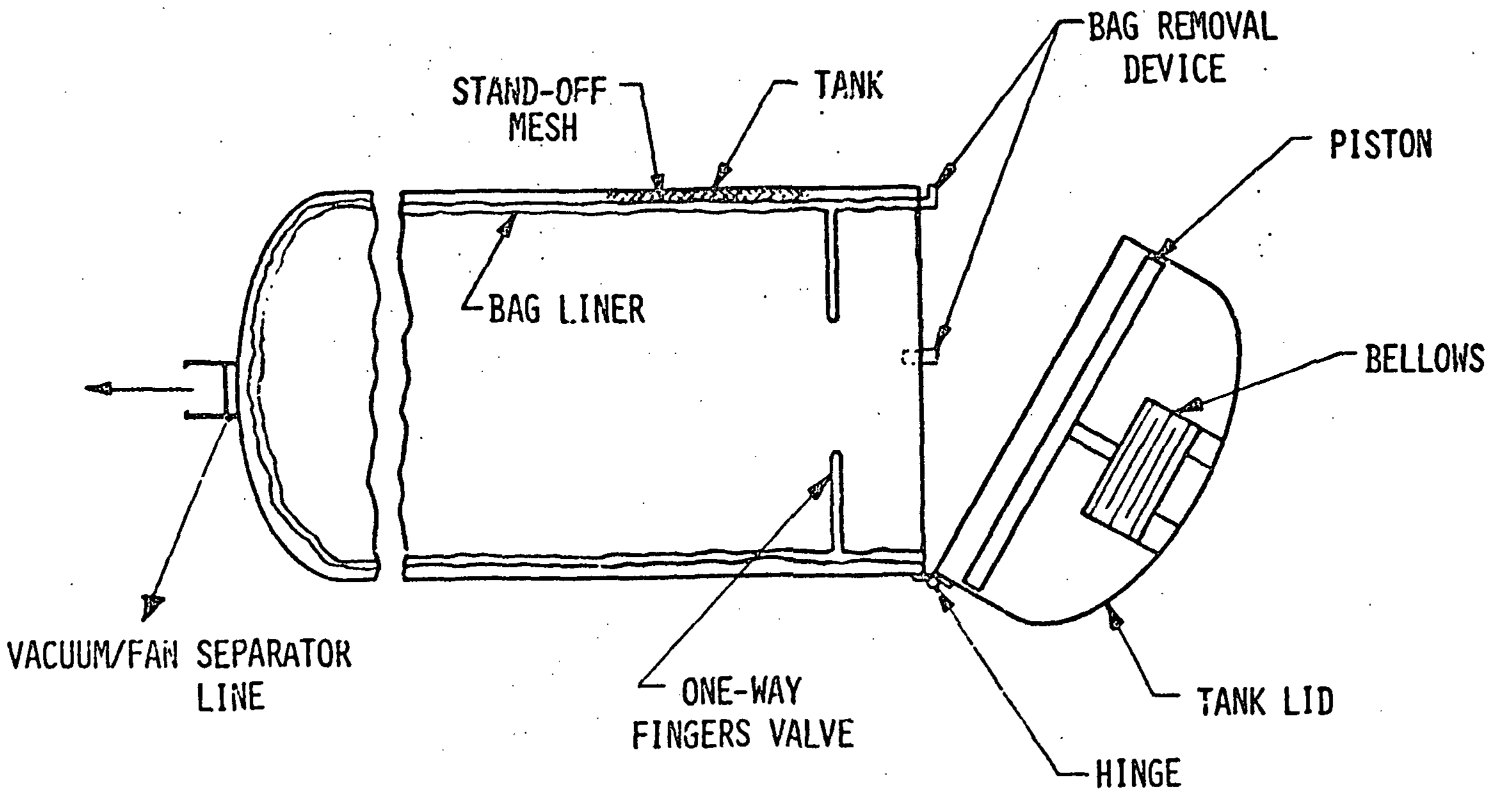


TYPICAL PISTON COMPACTOR

The illustration on the facing page shows a typical wipes tank with an integral piston compactor. The compactor piston is stroked by tank evacuation or mechanical manual backup. Upon piston actuation, the piston compacts the deposited wipes into the wipes tank bag liner past a one-way fingers valve, which retains the compacted wipes in the bag liner.

The tank and bag liner shape are typical. The tank is split to facilitate bag removal and replacement.

TYPICAL PISTON COMPACTOR



THREE-TANK COMPACTOR SYSTEM CONCEPT

The three-tank compactor system concept is a representative implementation for separated storage of feces and all wipes. Considering storage volume requirements, packaging, and in-flight serviceability, General Electric implemented this concept with three containment vessels instead of two, although the concept may be typified with a two-tank system.

Significantly, only feces and those wipes associated with fecal separation are deposited in the fecal tank. No compaction of this material is incorporated, as its volume is relatively definable and ideally 1 ft^3 for typical usage for 210 man-days. The contents of this vessel are vacuum dried.

All other wipes are deposited into the wipe tank(s). The representative implementation incorporates two wipes tanks for ease of packaging and in-flight handling. Piston compaction is depicted for the wipes tanks. The contents of these vessels are vacuum dried.

Access to both the fecal tank and a wipes tank is required during the defecation process, and access to a wipes tank is required during the urination cleansing process.

THREE TANK COMPACTOR SYSTEM CONCEPT

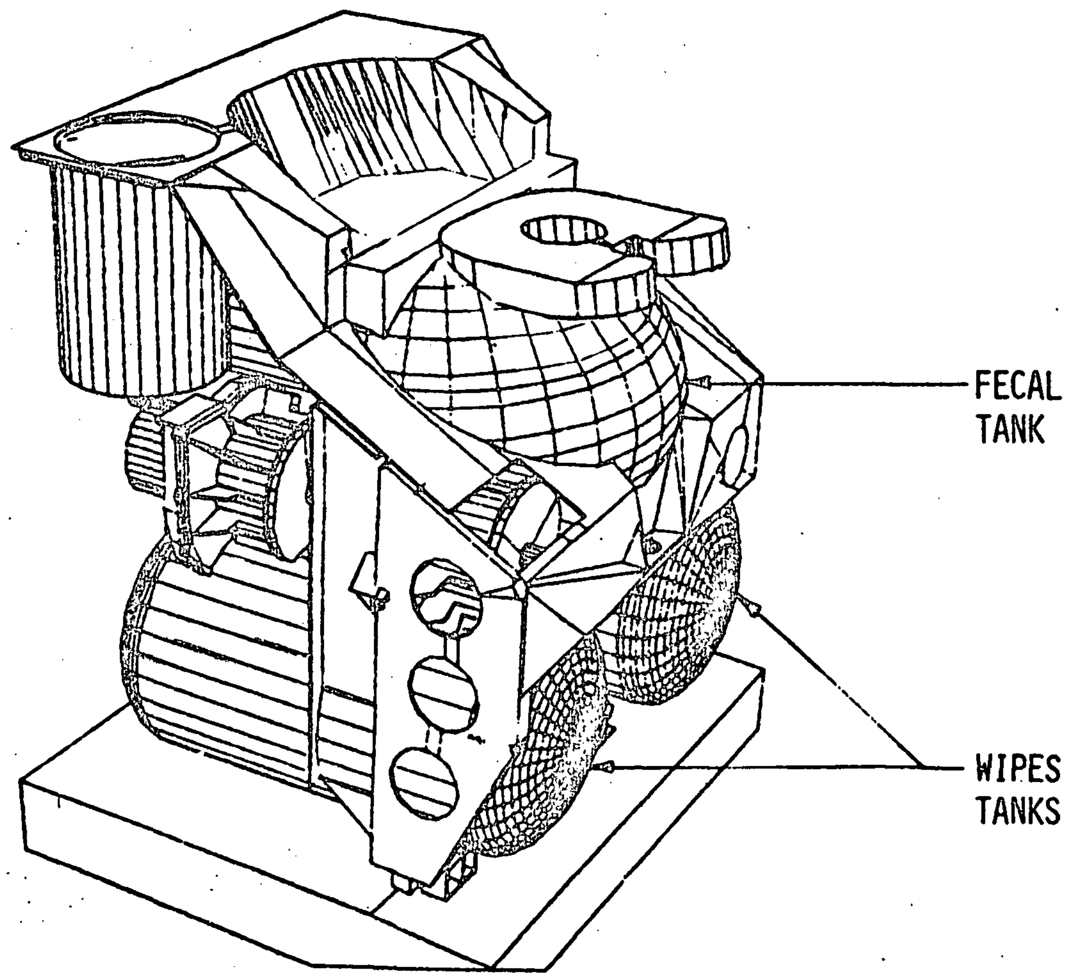
- THREE SOLID WASTE CONTAINMENT VESSELS.
  - FECES DEPOSITED IN FECAL WASTE CONTAINMENT VESSEL (NO COMPACTION).
  - FECAL WIPES AND URINE WIPES DEPOSITED IN EITHER OF TWO REDUNDANT WIPES CONTAINMENT VESSELS WITH PISTON COMPACTORS.

TYPICAL THREE TANK COMPACTOR SYSTEM CONCEPT CONFIGURATION

This chart presents a Computer Aided Engineering (GEOMOD) representation of the Three Tank Compactor Concept, and illustrates a representative packaging of this concept within the current WCS housing.

The fecal tank, sized in this configuration at 1.25 ft^3, accommodates feces and fecal separation wipes in an uncompacted state, while the wipes tanks, each sized with a usable volume of 1 ft^3, accommodate all wipes in a compacted state. All tanks are vacuum-dried.

TYPICAL THREE TANK COMPACTOR SYSTEM CONCEPT CONFIGURATION



TYPICAL PISTON COMPACTOR

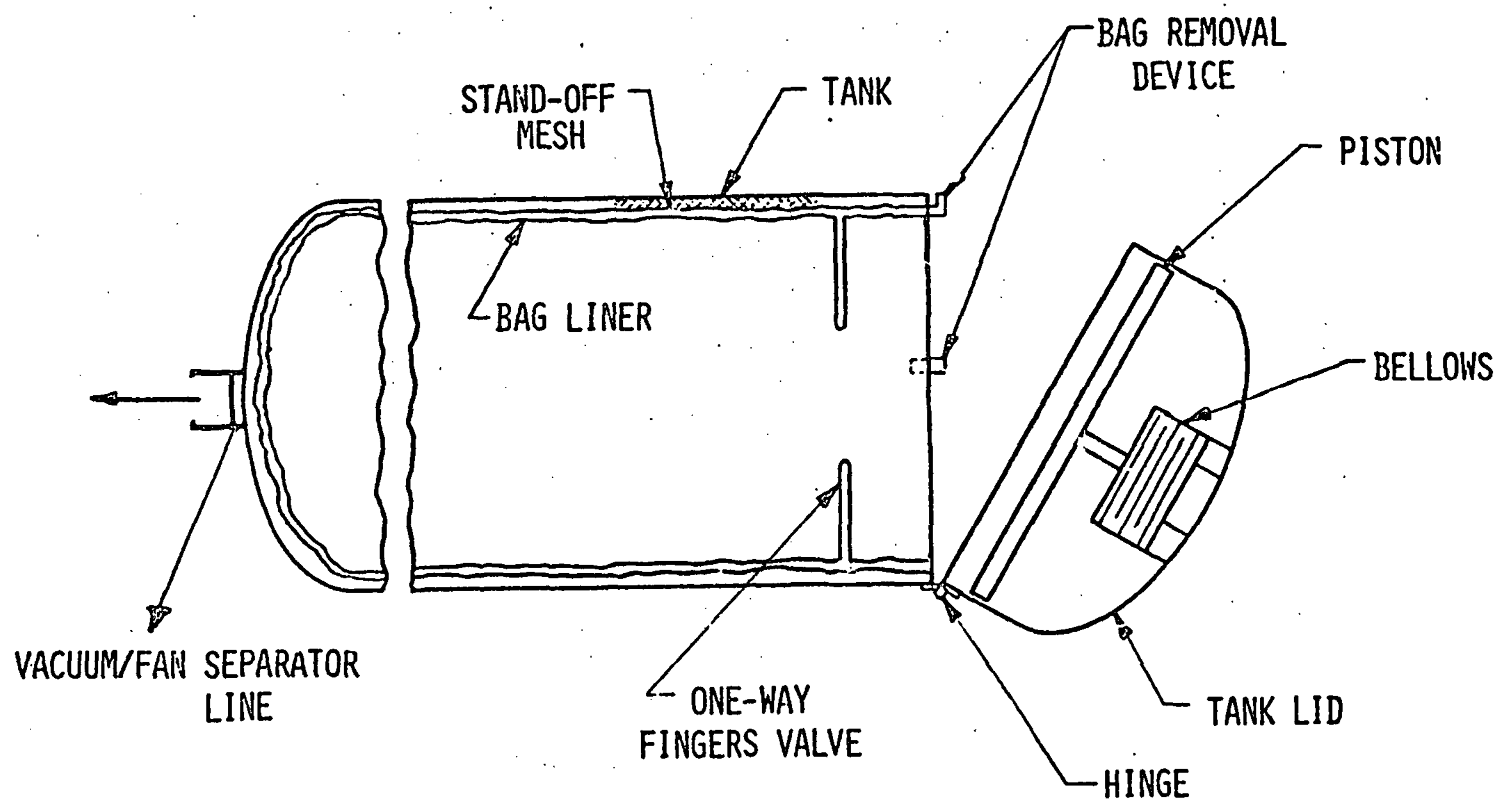
The illustration on the facing page shows a typical wipes tank with an integral piston compactor. The compactor piston is stroked by tank evacuation or mechanical manual backup. Upon piston actuation, the piston compacts the deposited wipes into the wipes tank bag liner past a one-way fingers valve, which retains the compacted wipes in the bag liner.

The tank and bag liner shape are typical. The tank is split to permit easy bag liner removal and replacement.

HOUSTON OPERATIONS

SPACE SYSTEMS DIVISION

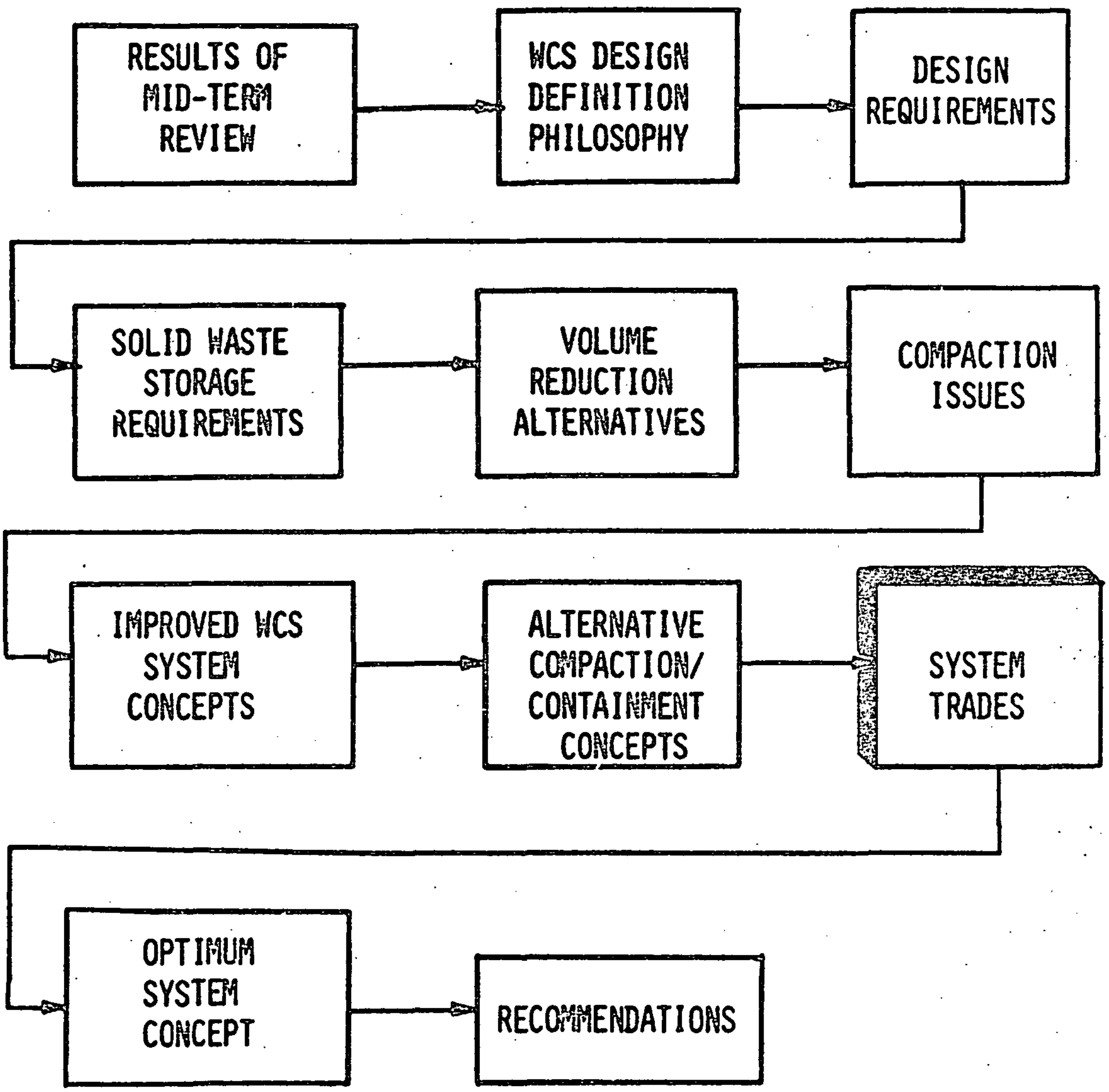
TYPICAL PISTON COMPACTOR



SYSTEM TRADES

The following section presents the trade-offs of the alternative compaction/containment concepts. Additionally, the cabin air consumption issue and its impact on the Improved WCS System Concept is discussed.

FINAL PRESENTATION FLOW



TRADE-OFF CRITERIA

The trade-off criteria considered in the evaluation of the alternative compaction/containment concepts are presented in this chart.

TRADE OFF CRITERIA

- DESIGN RISK.
- DESIGN SIMPLICITY.
- PRODUCTION COST.
- RETROFITABILITY.
- SERVICEABILITY.
- CONTINGENCY OPERATING MODES.
- NOISE.
- WEIGHT.
- POWER CONSUMPTION.
- SIMILARITY TO "HOME" ENVIRONMENT.
- EASE OF OPERATION.
- BODY STABILIZATION.

TRADE OFF CRITERIA (CONTINUED)

- CREW INTERACTION WITH WASTES.
- SPACE STATION GROWTH POTENTIAL.
- FECES SEPARATION.
- WASTE COLLECTION.
- WASTE CONTAINMENT.
- WASTE DISPOSAL IN-FLIGHT.
- BACTERIA AND ODOR CONTROL.
- WASTE RECYCLING CAPABILITY.
- TRAINING REQUIREMENTS.
- CABIN CONTAMINABILITY.
- EXPENDABLES CONSUMPTION.

MINIMUM CAPACITY REQUIREMENTS

The minimum capacities of the containment vessels required for implementation of the three alternative compaction/containment concepts are presented in this chart. These capacities, based on rudimentary compaction tests with the current wipes, 100% fecal packing efficiency, compaction efficiency back to the original wipes packaging volume, and the usage rates as previously assumed, represent minimum containment vessel volumes to require no in-flight servicing (solely on a capacity basis). Note that potential air flow degradation as the containment vessels fill must be addressed in a detailed design study.

These volumes provided minimum requirements as bases for Computer Aided Engineering (GEOMOD) studies to determine the ability to package these requirements in the current WCS envelope.

C-2

MINIMUM CAPACITY REQUIREMENTS

CONCEPT	VOLUME REQUIREMENTS
SINGLE TANK COMPACTOR	1 TANK: 2.10 FT^3
DUAL COMPACTOR	1 FECAL & FECAL WIPES TANK = 1.33 FT^3 1 URINE WIPES TANK = 0.77 FT^3
THREE TANK COMPACTOR	1 FECAL TANK = 1 FT^3 2 WIPES TANKS = 0.55 FT^3/EACH

GUIDELINES:
(1) NO ROUTINE IN-FLIGHT SERVICEABILITY TO SATISFY CAPACITY REQUIREMENTS.
(2) BASED ON RUDIMENTARY COMPACTION TESTS.
(3) 100% COMPACTION EFFICIENCY.
(4) 100% FECAL PACKING EFFICIENCY.

TYPICAL CAPACITY REQUIREMENTS

This chart presents typical capacities of the containment vessels used in the three concepts.

These capacities, generated in GEOMOD packaging studies, provide configurations which may be packaged within the current WCS compartment.

Detailed studies should maximize the tank volumes to minimize the potential of in-flight service, requiring bag liner removal/replacement, and to accommodate packing inefficiencies.

TYPICAL CAPACITY REQUIREMENTS*

CONCEPT	TYPICAL STORAGE VOLUMES
SINGLE TANK COMPACTOR	1 TANK = 3.23 FT^3
DUAL COMPACTOR	1 FECAL & FECAL WIPES TANK = 1.75 FT^3 1 URINE WIPES TANK = 1 FT^3
THREE TANK COMPACTOR	1 FECAL TANK = 1.25 FT^3 2 WIPES TANKS = 1 FT^3/EACH

- *BASED ON GEOMOD PACKAGING STUDIES.
- ALL TANKS PROVIDE A VOLUME MARGIN OF AT LEAST 25% TO ACCOMMODATE PACKING INEFFICIENCIES.

CABIN AIR CONSUMPTION FOR TYPICAL VOLUME TANK SIZES (FT^3)

This chart presents cabin air consumption for each concept for 210 man-days of system usage, assuming:

- o Tanks are vacuum-dried when not in use by venting to space,
- o Usage rates are as previously described.

Based on similar usage criteria, the current WCS would use 552 ft^3. Note that this sumingly low figure, compared to those presented for the three concepts, results from the fact that urine wipes are not deposited in the current WCS. If the current configuration were to accommodate urine wipes and evacuation requirements were consistent with those imposed on the Improved WCS concepts, cabin air consumption of approximately 3,300 ft^3 would occur.

All calculations are conservative, in that empty containment vessels are assumed throughout the usage cycle.

CABIN AIR CONSUMPTION FOR TYPICAL VOLUME TANK SIZES (FT^3)

MODE / CONCEPT	PER MAN DAY	TOTAL	RELATIVE RANKING
SINGLE TANK COMPACTOR	22.6	4748	3
DUAL COMPACTOR	7.75	1628	2
THREE TANK COMPACTOR	7.25	1523	1

NOTE: CURRENT WCS USES 552 FT^3 CABIN AIR BASED ON SIMILAR UTILIZATION CRITERIA.

ASSUMPTIONS:

(1) MAN-DAY REQUIREMENTS BASED ON PREVIOUSLY SPECIFIED USAGE.

(2) ALL WCS CONTAMINANTS VACUUM-DRIED.

EXPENDABLES REQUIREMENTS

This chart presents the expendables requirements for the three concepts, and is based on the assumption that in-flight servicing is not required in any of the three concepts.

It is assumed that the compaction device internal to the bag liner in the first two concepts would be disposed, although the option could be exercised with proper design to remove, clean, and reuse the internal compaction device as part of the post flight servicing procedure.

EXPENDABLES REQUIREMENTS

CONCEPT	REQUIREMENTS
SINGLE TANK COMPACTOR	1 BAG LINER WITH INTERNAL COMPACTOR
DUAL COMPACTOR	1 BAG LINER IN URINE WIPES TANK 1 BAG LINER WITH INTERNAL COMPACTOR
THREE TANK COMPACTOR	1 FECAL TANK BAG LINER 2 WIPES TANK BAG LINERS

EXPENDABLES COST TRADES

This chart presents the ranking of the three concepts in order of increasing expendables cost. The three tank compactor concept is ranked least expensive.

Although this concept disposes of three bag liners per orbiter mission, the bag design, being simple bags with no internal compactors, are seen as being markedly less expensive to develop, fabricate, and qualify than the far more complicated bag with an internal compactor.

The dual compactor concept has a similar internal compactor bag to that used in the single compactor concept, and, in addition requires an expendable wipes tank bag liner. Therefore, it ranks highest in expendables cost.

EXPENDABLES COST TRADES

CONCEPT	REQUIREMENTS	RELATIVE RANKING
SINGLE TANK COMPACTOR	BAG LINER WITH INTERNAL COMPACTOR.	2
DUAL COMPACTOR	BAG LINER WITH INTERNAL COMPACTOR. URINE WIPES BAG LINER.	3
THREE TANK COMPACTOR	1 FECAL BAG LINER. 2 WIPES BAG LINERS.	1
	ODOR/BACTERIA FILTER NEUTRAL TO ALL SYSTEMS.	

POST-FLIGHT SERVICING TRADES

This chart presents a trade-off of the three concepts relative to post flight servicing. The concepts are ranked with regard to ease of post-flight servicing, and the three tank compactor concept is easiest with the dual compactor concept most difficult.

In that the three tank compactor concept utilizes no compaction devices internal to the bag liner and all containment vessels are split, the recommended post flight servicing methodology is to, in the Orbiter:

- o Remove the used bag liners,
- o Disinfect the system,
- o Replace the bag liners.

No tank removal is envisioned.

Both alternate concepts employ the internal compactor bag liners, and the recommended post-flight servicing procedure would be:

- o Removal of the fecal tank,
- o Out of Orbiter servicing of this element,
- o In Orbiter servicing of the remaining elements.

This minimizes risk of bag breakage within the Orbiter.

Internal compactor servicing is viewed as an option dependent on associated costs versus replacement expenses.

POST-FLIGHT SERVICING TRADES

CONCEPT	REQUIREMENTS	RELATIVE RANKING
SINGLE TANK COMPACTOR	TANK REMOVAL PREFERRED	2
DUAL COMPACTOR	FECAL TANK REMOVAL PREFERRED	3
THREE TANK COMPACTOR	IN VEHICLE SERVICING	1

TURNAROUND COST TRADES

This chart presents the results of a trade of the turnaround costs associated with the three concepts, and represents a summation of expenses associated with expendables and post-flight servicing.

The concepts are ranked in order of increasing turnaround costs, and the three tank compactor concept is seen as least expensive.

TURNAROUND COST TRADES

- SUM OF EXPENDABLES + POST-FLIGHT SERVICING

CONCEPT	RELATIVE RANKING
SINGLE TANK COMPACTOR	2
DUAL COMPACTOR	3
THREE TANK COMPACTOR	1

DESIGN RISK

This chart identifies those new design elements present in each of the alternative concepts, and ranks the relative design risk associated with each of the concepts.

The single tank compactor and dual compactor concepts both use bag liners with internal compactors and the major design risks associated with this element are:

- o complex bag liner/internal compactor design
- o risk of bag breakage during use

Additionally, both these concepts compact feces and the design must ensure no bag liner clogging with associated air flow degradation resultant from this process.

Both dual compactor and three-tank compactor concepts use a piston compactor for wipes compaction. This compaction methodology and its associated risks are significantly reduced as compared to those associated with an internal compactor. Additionally, the piston compactors do not compact feces, and hence, potential contamination is significantly reduced.

The three-tank compactor concept uses redundant piston compactors, with manual overrides to eliminate the potential of compaction failure.

The three-tank compactor concept is seen as the lowest risk, with the dual compactor concept, incorporating both new design elements of the other concepts, seen as the highest risk.

DESIGN RISK

CONCEPT	REQUIREMENTS	RELATIVE RANKING
SINGLE TANK COMPACTOR	FECAL COMPACTION. COMPLEX BAG LINER/INTERNAL COMPACTOR.	2
DUAL COMPACTOR	FECAL COMPACTION. PISTON COMPACTOR. COMPLEX BAG LINER/INTERNAL COMPACTOR	3
THREE TANK COMPACTOR	PISTON COMPACTOR.	1
	OTHER NEW ELEMENTS COMMON TO ALL SYSTEMS.	

IN-FLIGHT SERVICEABILITY TRADES

The trades of the three concepts related to ease of in-flight servicing addressed four issues:

- o ease of servicing
- o storage requirements for replaceable elements
- o risks associated with in-flight servicing
- o stowage of degraded (used) elements

All three concepts provide capability for bag liner replacement and odor/bacteria filter replacement.

Odor/bacteria filter replacement is seen as comparable with all three concepts.

Servicing requirements for each of the concepts is presented in the chart.

The storage, handling, replacement, and contamination potential attached to the bag liner/internal compactor configuration is significant compared to those associated with the three-tank compactor concept, where feces are left undisturbed. Additionally, potential for requiring in-flight servicing is significantly increased when the fecal material is compacted. This would necessitate handling of the bag containing feces.

These internal compactor bag liners additionally are much more difficult to stow and replace to ensure the necessary compaction capability.

Consequently, the three-tank compactor concept is ranked as a <u>significantly</u> easier concept to service in-flight.

IN-FLIGHT SERVICEABILITY TRADES

CONCEPT	REQUIREMENTS	RELATIVE RANKING
SINGLE TANK COMPACTOR	REPLACEMENT OF LARGE FECAL BAG WITH INTERNAL COMPACTOR. STORAGE AND HANDLING OF CONTAMINATED ELEMENTS. STORAGE, ASSEMBLY AND INSTALLATION OF NEW BAGS AND COMPACTOR.	3
DUAL COMPACTOR	REPLACEMENT OF ONE MODERATE SIZE FECAL BAG WITH INTERNAL COMPACTOR. REPLACEMENT OF ONE MODERATE SIZE URINE WIPES BAG. STORAGE AND HANDLING OF BAGS. STORAGE, ASSEMBLY AND INSTALLATION OF NEW BAGS AND COMPACTOR.	2
THREE TANK COMPACTOR	REPLACEMENT OF ONE MODERATE SIZE FECAL BAG. REPLACEMENT OF TWO MODERATE SIZE WIPES BAGS. STORAGE AND HANDLING OF BAGS. STORAGE AND INSTALLATION OF NEW BAGS.	1
	NON-POROUS CONTAINMENT BAGS WITH ONE-WAY VALVES PROVIDED FOR FILTER BAG LINER STORAGE. NO SIGNIFICANT DIFFERENCE IN SERVICEABILITY OF ODOR/BACTERIA FILTERS BETWEEN CONCEPTS.	

DEVELOPMENT COSTS TRADES

This chart presents the major element development requirements for each of the three concepts and ranks the three concepts in order of increasing development costs.

The development of a satisfactory bag liner/internal compactor configuration is seen as a major development item in the first two Improved WCS Concepts. All concepts require split tank development; two tank designs required in the two and three-tank concepts, while only one is required in the single tank concept.

Both two and three tank concepts require the development of a relatively simple piston compactor.

Note that the dual compactor concept requires development of all elements in both the one tank and three-tank concepts.

In view of the complexity attached to the development of the bag liner/internal compactor, the three-tank compactor concept is seen as being least costly to develop, with the dual compactor concept most expensive.

DEVELOPMENT COSTS TRADES

CONCEPT	REQUIREMENTS	RELATIVE RANKING
SINGLE TANK COMPACTOR	1 TANK FECAL TANK BAG LINER WITH INTERNAL COMPACTOR	2
DUAL COMPACTOR	2 TANKS FECAL BAG LINER WITH INTERNAL COMPACTOR URINE WIPES TANK BAG LINER PISTON COMPACTOR	3
THREE TANK COMPACTOR	2 TANKS FECAL BAG LINER WIPES TANK BAG LINER PISTON COMPACTOR	1
	DEVELOPMENT COSTS DELTAS OF OTHER SYSTEMS ELEMENTS BETWEEN CONCEPTS ASSUMED NEGLIGIBLE	

COMPACTOR CONTINGENCY OPERATION TRADES

This chart presents the impact of compactor failure by indicating compactor contingency operation modes along with the effects of compactor failure.

Compactor failure in the single tank concept results in degradation to the current WCS configuration, with frequent bag liner changes to provide 210 man-days of usage.

Failure of the fecal tank compactor in the dual compactor concept results in elimination of this capability, and all wipes should subsequently be deposited in the wipes compactor. Note, however, that fecal tank bag liner servicing most probably would be required (depending on when in the course of the mission the failure occurred). Failure of the wipes compactor would necessitate frequent in-flight replacement of the wipes bag liner.

The three-tank compactor concept incorporates no compaction of the fecal waste, and hence, this element is significantly unaffected by a compactor failure. Compaction is incorporated in redundant wipes tank, with redundant manual overrides. Hence, compaction failure probably in this simple concept is minimal, and would result in wipes bag liner replacement.

Hence, the three-tank compactor concept is significantly advantageous over the other two concepts in reduced probability of compactor failure, and the minimal impact such a failure would have on continued satisfactory system performance.

COMPACTOR CONTINGENCY OPERATION TRADES

CONCEPT	COMPACTOR CONTINGENCY OPERATION MODES	RELATIVE RANKING
SINGLE TANK COMPACTOR	• COMPACTOR FAILURE RESULTS IN INCREASED BAG LINER/COMPACTOR CHANGES	3
DUAL COMPACTOR	• FECAL TANK COMPACTOR FAILURE RESULTS IN: - THREE TANK OPERATING MODE WITH INCREASED BAG LINER CHANGES - INCREASED FECAL TANK/COMPACTOR BAG LINER CHANGES • NO REDUNDANT WIPES COMPACTION CAPABILITY	2
THREE TANK COMPACTOR	• NO COMPACTION OF FECAL WASTES • REDUNDANT WIPES COMPACTION	1

EASE OF OPERATION TRADES

The major differences in crew usage between the three concepts are identified in this chart and the three concepts are ranked on this basis.

The single tank concept is used similar to the current WCS. The commode additionally is opened to accommodate urine wipes.

In the dual compactor concept, fecal wipes are deposited in the fecal tank under the crew member, whereas all wipes are deposited in the wipes tanks in the three-tank concept.

A survey of individuals indicated no significant preference in the location for fecal wipes deposition.

Hence, solely on the basis of similarity to the current system is the single tank concept judged simplest to operate. As indicated, however, this trade did not present significant variation among the three concepts.

EASE OF OPERATION TRADES

CONCEPT	REQUIREMENT	RELATIVE RANKING
SINGLE TANK COMPACTOR	• SIMILAR TO CURRENT SYSTEM	1
DUAL COMPACTOR	• DEPOSIT URINE WIPES IN SEPARATE HOLE	2
THREE TANK COMPACTOR	• DEPOSIT FECAL AND URINE WIPES IN SEPARATE HOLE	2

DIFFERENCES VERY SMALL AND USER DEPENDENT.

CONTAMINATION POTENTIAL TRADES

This chart identifies potential sources of contamination for each of the three concepts and ranks the concepts in order of increasing contamination risk.

The single tank and dual compactor concepts, as a result of fecal waste compaction, potentially may require in-flight servicing, which presents a significant risk due to the complicated handling of this type of bag liner design and the size of the bags. Additionally, potential contamination due to bag breakage is significant.

The three-tank compactor concept presents some contamination risk if the crew retains its defecation orientation during the fecal wipe process, in that possible contamination of the WCS area may occur in transporting a wipe from the buttock area to a wipes tank.

In-flight bag replacement in the three-tank concept should not require handling of the fecal bag as no compaction process is incorporated, and bag sizing should be such as to accommodate any fecal packing inefficiencies.

The three-tank compactor concept is considered the minimum risk of the three concepts with regard to contamination potential.

CONTAMINATION POTENTIAL TRADES

CONCEPT	CONTAMINATION POTENTIAL	RELATIVE RANKING
SINGLE TANK COMPACTOR	• USAGE SIMILAR TO CURRENT WCS • BAG BREAKAGE RISK IN TRANSFER HIGH	2
DUAL COMPACTOR	• USAGE SIMILAR TO CURRENT WCS • BAG BREAKAGE RISK IN TRANSFER HIGH	3
THREE TANK COMPACTOR	• POSSIBLE CONTAMINATION IN FECAL WIPE PROCESS • BAG BREAKAGE RISK IN TRANSFER LOW	1

URINE WIPES CONTAMINATION POTENTIAL REDUCED AS COMPARED TO CURRENT DESIGN.

PRODUCTION COST TRADES

This chart presents the production requirements for the alternative Improved WCS concepts, and ranks the concepts in order of increasing production costs. All system elements not included as production requirements are neutral to the three concepts.

The dual compactor concept, incorporating all elements of both alternative concepts, is most expensive.

The single tank compactor concept and the three-tank compactor are viewed as insignificantly different in production costs primarily resultant from the complexity and expense associated with the internal bag liner/compactor element.

PRODUCTION COST TRADES

CONCEPT	REQUIREMENT	RELATIVE RANKING
SINGLE TANK COMPACTOR	• BAG LINER WITH INTERNAL COMPACTOR • TANK	1
DUAL COMPACTOR	• BAG LINER WITH INTERNAL COMPACTOR • BAG LINER FOR URINE WIPES • 1 FECAL TANK • 1 PISTON COMPACTOR WIPES TANK	2
THREE TANK COMPACTOR	• BAG LINER FOR FECAL TANK • 2 IDENTICAL BAG LINERS • 1 FECAL TANK • 2 IDENTICAL WIPES TANKS	1
	ALL OTHER ELEMENTS EITHER NEUTRAL OR INSIGNIFICANT DIFFERENCE.	

SYSTEM WEIGHT CONSIDERATIONS

The total Improved WCS weight was identified as a non-critical issue, although any detailed design should minimize this system parameter.

In considering the three concepts, the elements which vary weight-wise between them are:

- o tanks
- o compactors
- o bag liners

The tank weight represents the most significant weight element of these three items. This trade item was not evaluated, as specific tank weights are detailed design dependent, and the large variation in proposed tank sizes does not necessarily support three tanks being heavier than either one or two.

SYSTEM WEIGHT CONSIDERATIONS

- ALL CONCEPTS HAVE SAME WEIGHT RELATIVE TO COMMON SYSTEM ELEMENTS.
- TANK WEIGHT DETAILED DESIGN DEPENDENT.
- TOTAL WCS SYSTEM WEIGHT NOT CRITICAL SYSTEM LIMITATION.

POWER REQUIREMENT TRADES

The three concepts have no non-common elements which have power requirements, and therefore, the concepts require identical power levels.

POWER REQUIREMENT TRADES

- ALL CONCEPTS REQUIRE IDENTICAL POWER LEVELS.

SIMILARITY TO "HOME" ENVIRONMENT

The defecation, urination, and associated cleansing processes in a zero-g environment are significantly different from performance of these same processes in a one-g environment.

The differences between the three concepts rests solely on where the cleansing wipes are deposited. In the single tank compactor concept, all wipes are deposited in the single tank. In the dual compactor concept, the fecal wipes are deposited in the same opening in which the feces are deposited, while the fecal wipes are deposited in either of two wipes tanks in the three-tank concept, separated from the feces. In both these latter cases, urine wipes are addressed similarly, being placed in the wipes tank.

In that the crew cannot readily perform the cleansing function while seated on the WCS, no increased similarity to "home" environment was perceived in any concept. This was confirmed in a survey of 21 people.

SIMILARITY TO "HOME" ENVIRONMENT

- NONE ARE SIMILAR.
- EVALUATION VERY USER DEPENDENT

OTHER TRADES

No significant differences among the three alternatives were perceived relative to the trade issues presented in this chart.

OTHER TRADES

- SYSTEM CONCEPTS EXHIBIT NO SIGNIFICANT DIFFERENCES RELATIVE TO:
  - NOISE
  - BODY STABILIZATION
  - FECES SEPARATION
  - WASTE CONTAINMENT
  - WASTE DISPOSAL
  - BACTERIA AND ODOR CONTROL
  - RETROFITABILITY
  - CREW INTERACTION WITH WASTES
  - TRAINING REQUIREMENTS

CONCEPT TRADE SUMMARY

This chart summarizes the results of the trades of the three alternatives. Clearly, the three-tank compactor concept is the optimal concept. Scoring ahead in all trade categories except for ease of operation. This criteria was a very subjective one, with varied positions by individuals surveyed.

An attempt was made to prioritize and weight the trade-off criteria, and the results of surveying of people were quite varied. As the study results so clearly present the three-tank concept (separated feces and all wipes) as optimum, extensive efforts toward the prioritization and weighting of trade-off criteria were not made.

CONCEPT TRADE SUMMARY

TRADE CRITERIA / CONCEPT	CABIN AIR CONSUMPTION	EXPENDABLES COST	POST FLIGHT SERVICING	TURNAROUND COSTS	DESIGN RISK	IN-FLIGHT SERVICEABILITY	DEVELOPMENT COSTS	COMPACTOR CONTINGENCY OPERATION	EASE OF OPERATION	CONTAMINANT POTENTIAL	PRODUCTION COSTS
SINGLE TANK COMPACTOR	3	2	2	2	2	3	2	3	1	2	1
DUAL COMPACTOR	2	3	3	3	3	2	3	2	2	3	3
THREE TANK COMPACTOR	1	1	1	1	1	1	1	1	2	1	1

- PRIORITIZATION OF TRADE CRITERIA VERY SUBJECTIVE.
- TRADE OFF RESULTS DID NOT SUPPORT EXTENSIVE EFFORTS TOWARD THAT GOAL.

CABIN AIR CONSUMPTION ISSUE

Desiring to minimize cabin air consumption and identifying this as a potential issue in the vacuum drying of the solid waste materials, a vacuum pump was included in the Improved WCS as an alternative to vacuum venting to space.

The vacuum pump is implemented in the system, evacuating any of the tanks and passing the evacuated air through the odor/bacteria filter back to the cabin. This process essentially eliminates cabin air loss from the Improved WCS evacuation process.

This chart presents a trade-off of the inclusion of a vacuum pump versus vacuum venting to space.

Note that the evacuation process does not sterilize the contaminated material, but dries the waste, resulting in reduced reproductive and metabolic rates and reduced associated by-products.

Additionally, the inclusion of a vacuum pump provides the ability to eliminate vacuum venting to space, a Space Station requirement, the Improved WCS, with this inclusion, becomes a viable Space Station WCS configuration as required by the Statement of Work and allows the demonstration of this concept in a Shuttle Orbiter environment.

This option is recommended for inclusion as part of the optimum Improved WCS concept as the added weight and complexity of its inclusion are minimal penalties compared to the flexibility it adds related to frequency of evacuation, the redundancy, and the ability it adds to gather needed data related to Space Station goals.

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CABIN AIR CONSUMPTION ISSUE

- MINIMAL CABIN AIR USAGE DESIRABLE.

VACUUM PUMP TO CABIN VS. VACUUM VENTING TO SPACE

VACUUM PUMP TO CABIN

ADVANTAGES	DISADVANTAGES
- NO CABIN AIR LOSS	- ADDITIONAL WEIGHT
- ABILITY TO VACUUM DRY ALL SOLID WASTES FOR BACTERIAL DEACTIVATION	- ADDITIONAL COMPLEXITY
- OPTION THROUGH ADDITIONAL VALVES TO VENT TO VACUUM IN EVENT OF ODOR PROBLEM	- POTENTIAL ODOR PROBLEM
- REDUNDANT EVACUATION CAPABILITY	- INCREASED POWER
	- INCREASED CABIN AIR HUMIDITY

VACUUM VENTING TO SPACE

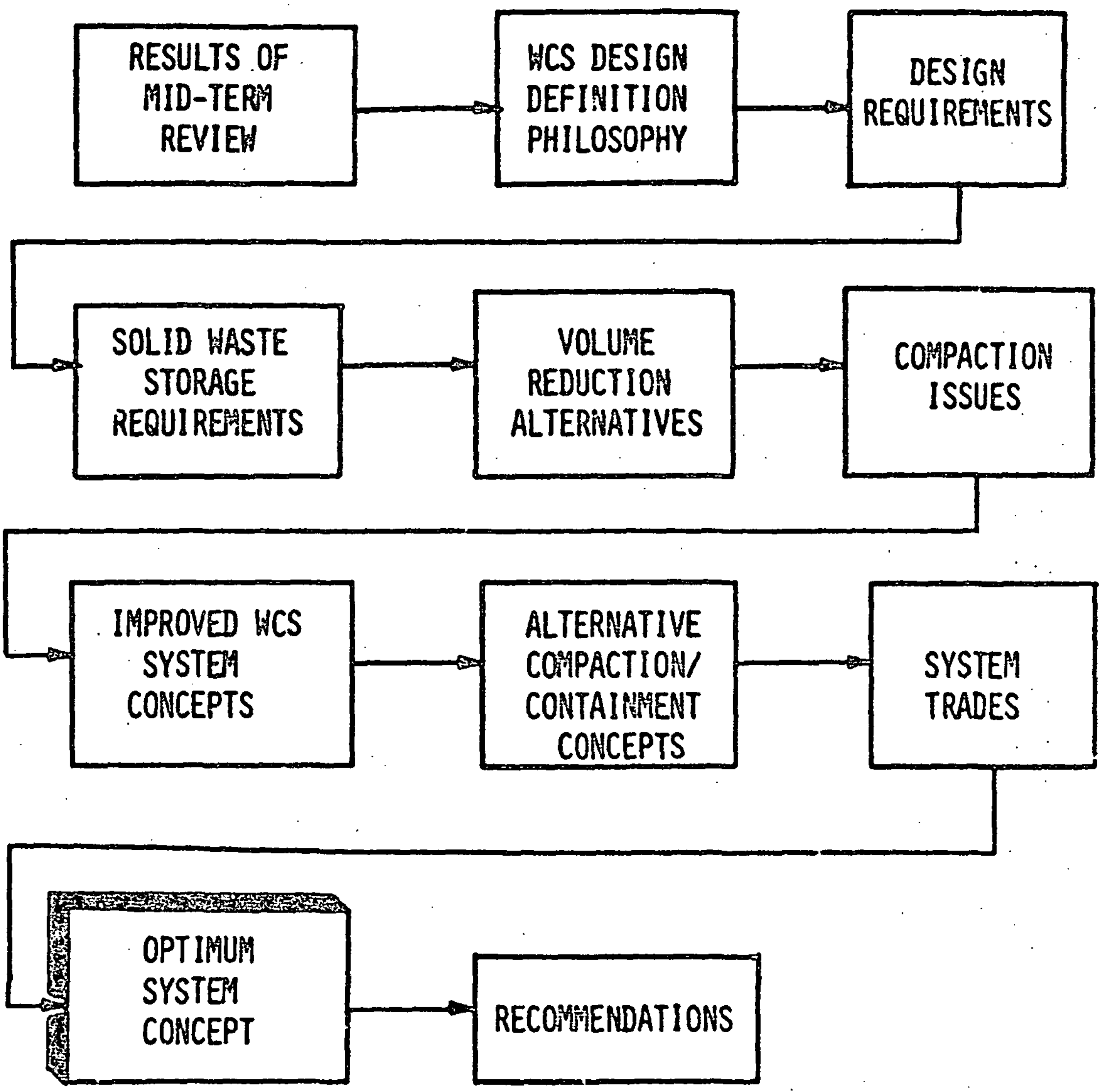
ADVANTAGES	DISADVANTAGES
- SIMPLER	- CABIN AIR LOSS
- LIGHTER	- VALVE FAILURE IN OPEN POSITION ELIMINATES VACUUM DRYING CAPABILITY

CONCLUSION: VACUUM PUMP SHOULD BE INCORPORATED.

OPTIMUM SYSTEM CONCEPT

This section discusses the optimum Improved WCS concept - separated, uncompacted feces and compacted wipes in a three-tank compactor design, system elements, and the Improved WCS modes of operation.

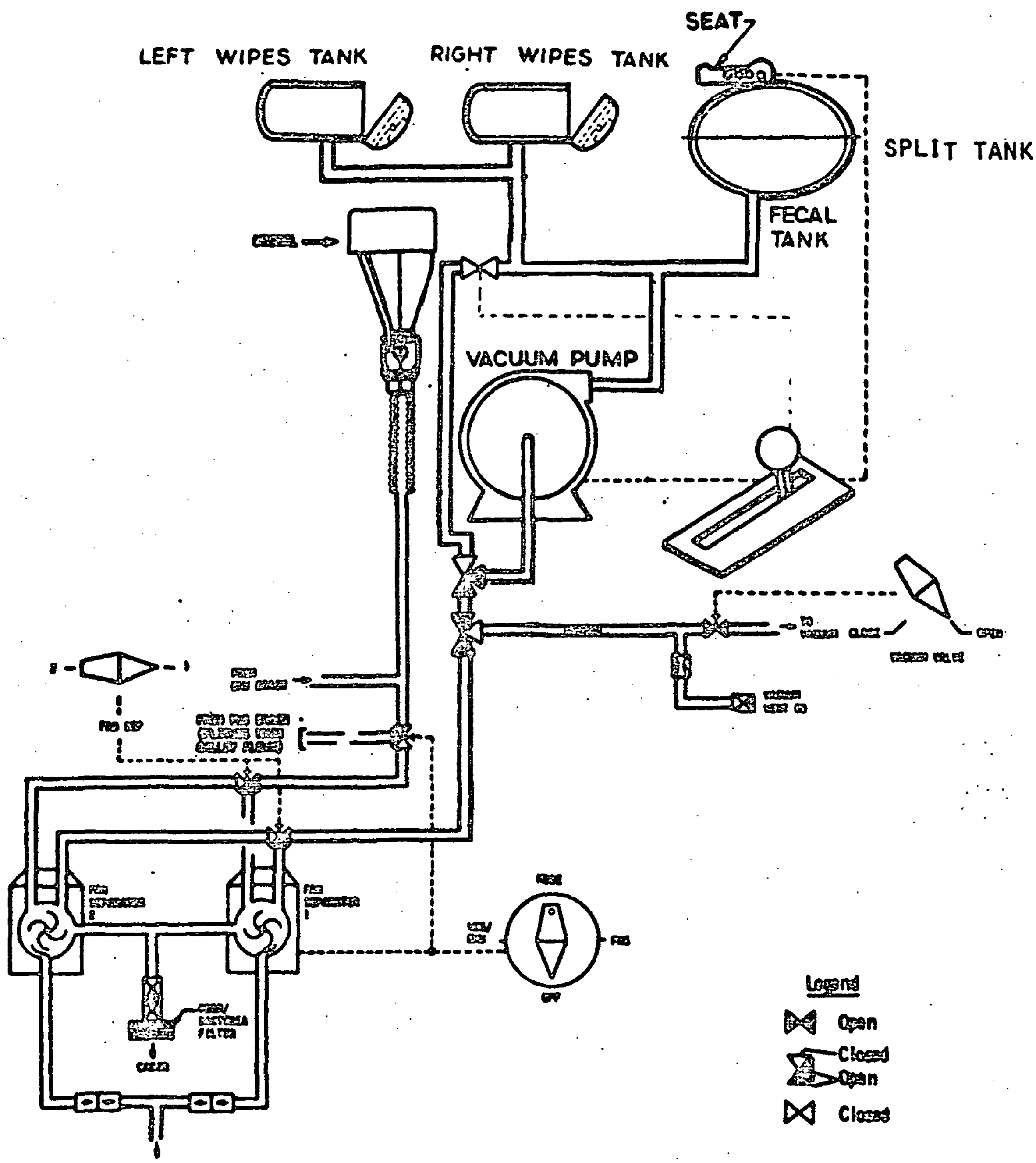
FINAL PRESENTATION FLOW



THREE TANK COMPACTOR - THE OPTIMUM SYSTEM CONCEPT

The optimum system concept for an Improved WCS is presented on the facing page. The concept resolves the capacity issue by replacing the current fixed capacity tank, 2.65 ft^3 volume, with a three-tank variable capacity system, where the fecal tank collects fecal waste and wipes associated with removal of final portion of each fecal deposit from the anus, and the left and right wipes tanks, which collect and compact all other wipes. This concept provides a total system storage capacity of 4.3 ft^3. The system concept incorporates a vacuum pump to evacuate the fecal and wipes tanks and can be configured to be operated on an on-demand basis. The remainder of the current Improved WCS is retained except for modification in valving and controls necessitated by the Improved WCS modes of operation.

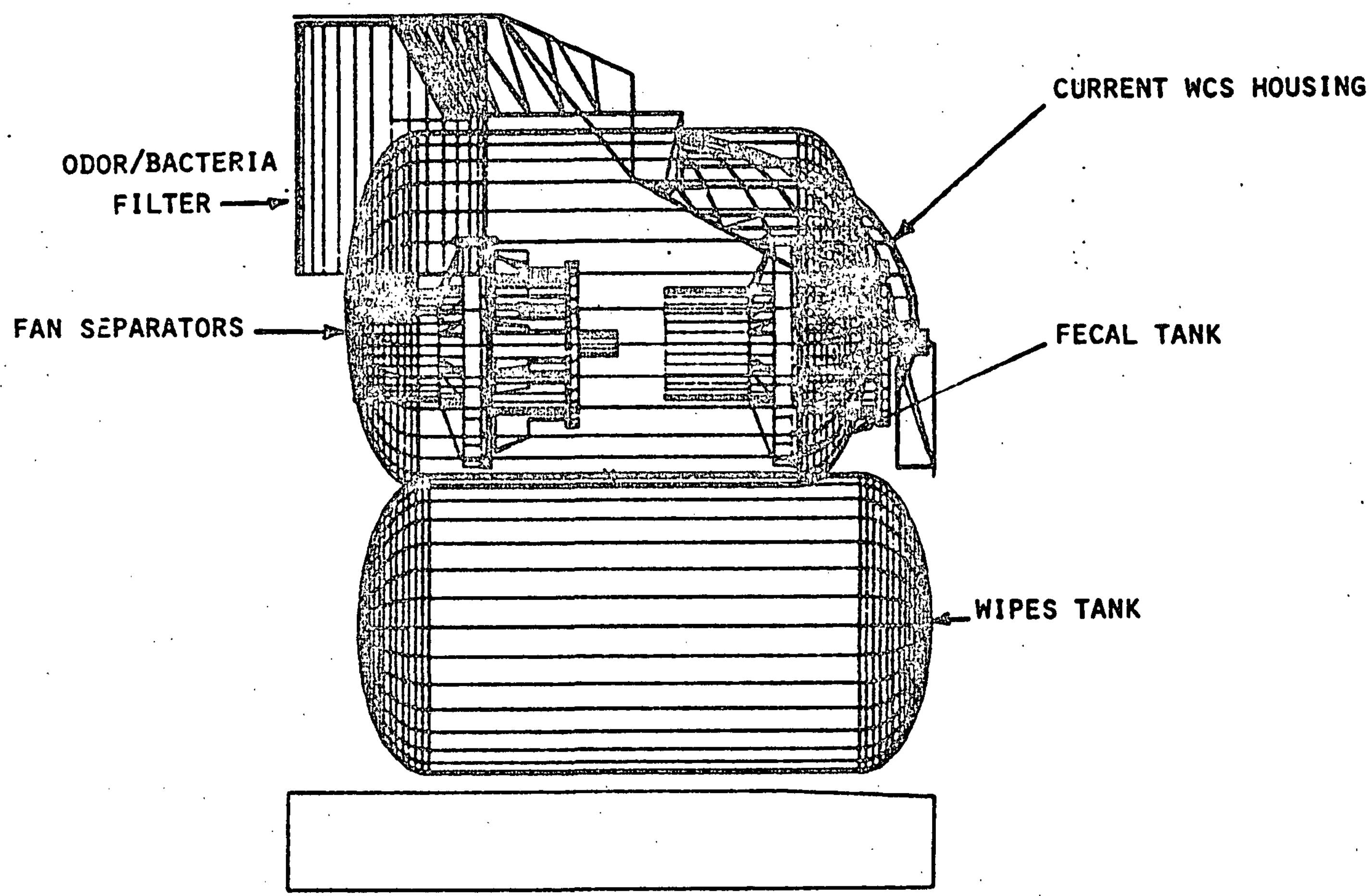
THREE TANK COMPACTOR - THE OPTIMUM SYSTEM CONCEPT



TYPICAL THREE-TANK CONFIGURATION WITHIN CURRENT WCS COVER

This GEOMOD packaging study output presents a representative packaging of the Improved WCS System Concept within the current WCS cover. This illustrates that the Improved WCS System Co..cept can fit within the current WCS envelope. In addition, the storage volume for the Improved WCS concept is greater than the requirements previously presented.

TYPICAL THREE TANK CONFIGURATION WITHIN CURRENT WCS COVER



IMPROVED WCS SYSTEM ELEMENTS

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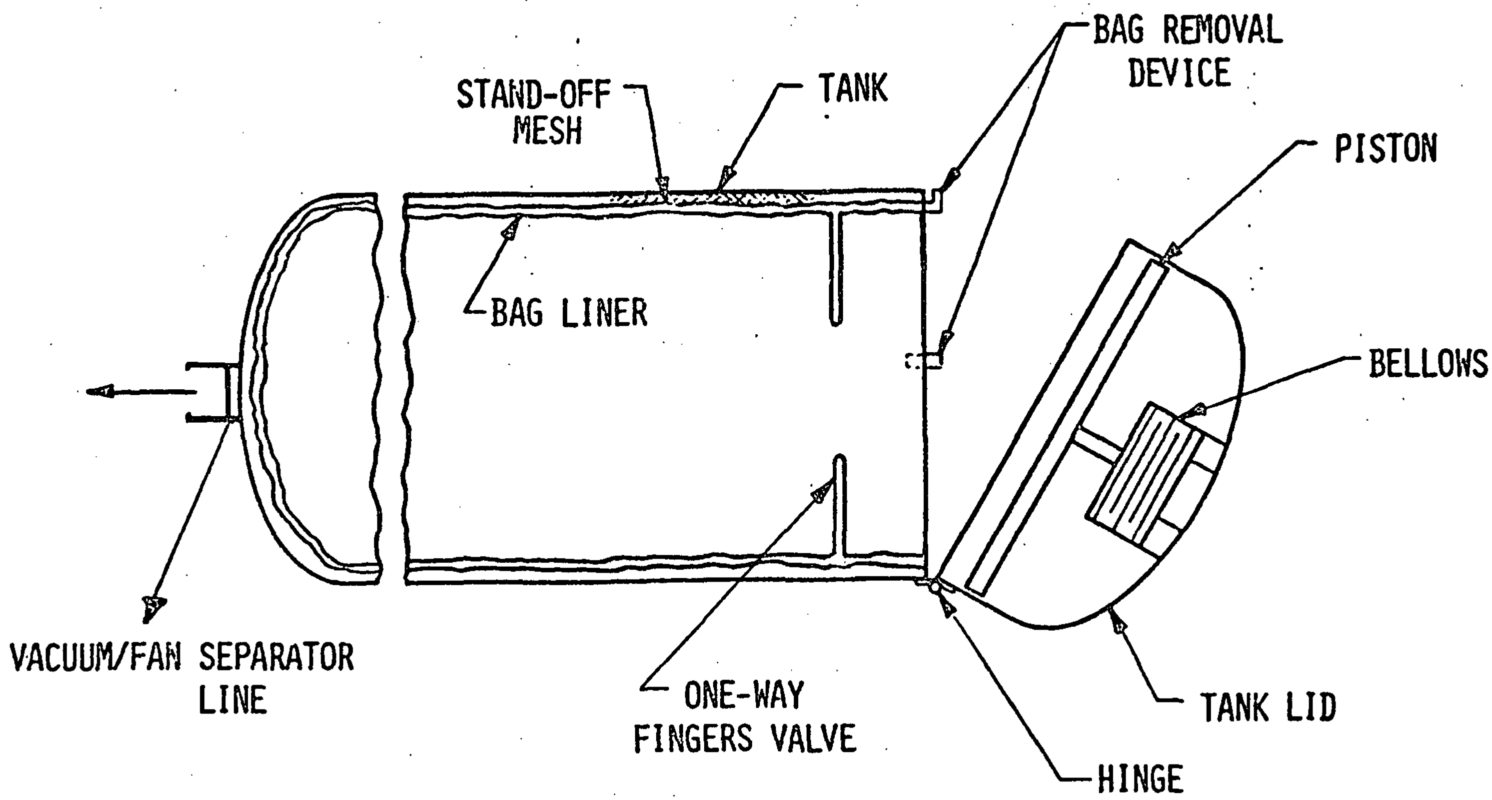
TYPICAL PISTON COMPACTOR

The illustration on the facing page shows a representative wipes tank with an integral piston compactor. The compactor piston is stroked by tank evacuation or mechanical manual back-up. Upon piston actuation, the piston compacts the deposited wipes into the wipes tank bag liner past a one-way fingers valve, which retains the compacted wipes in the bag liner.

The tank and bag liner shape are typical. However, the tank should be split to allow for simple bag liner removal and replacement.

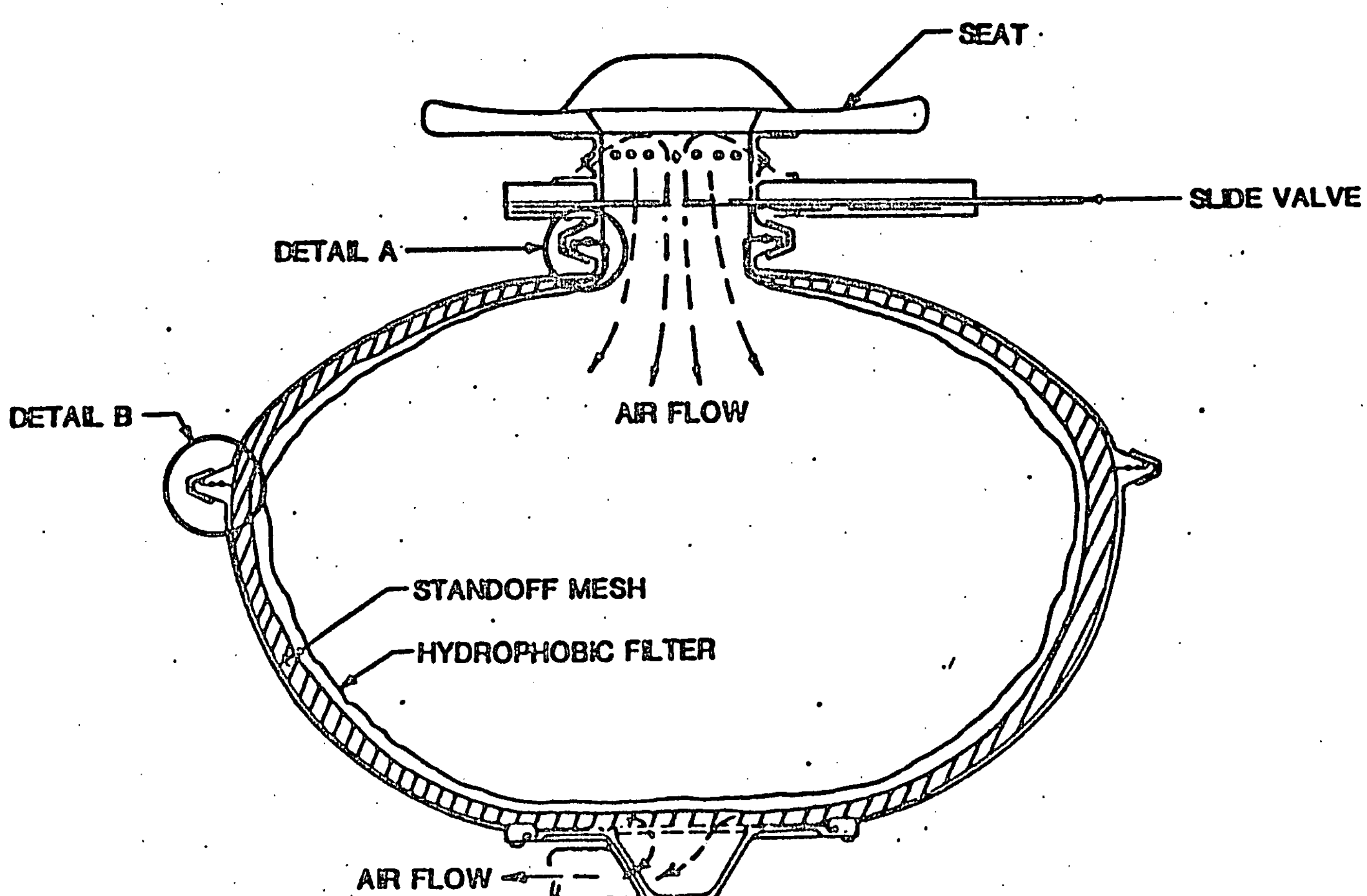
TYPICAL PISTON COMPACTOR



SPLIT TANK CONCEPT

The illustration on the facing page shows the split tank concept, which is required in the Improved WCS Concept for simple bag liner removal and replacement. In the Improved WCS Concept, both wipes tanks are split and hinged to allow for bag liner servicing and wipes deposition, respectively. The fecal tank is also split to allow for bag liner servicing. The depicted tank illustrates the split tank concept, and is representative for the Improved WCS System Concept.

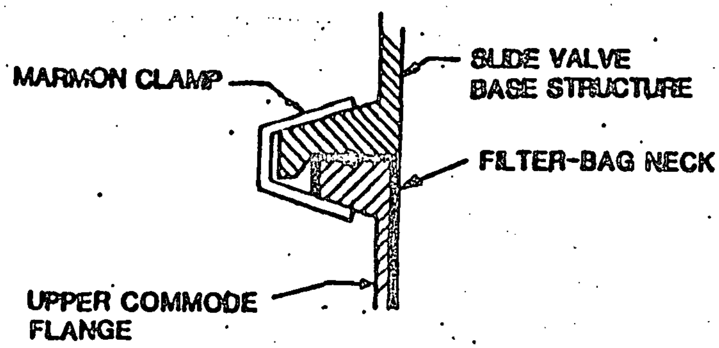
SPLIT TANK CONCEPT



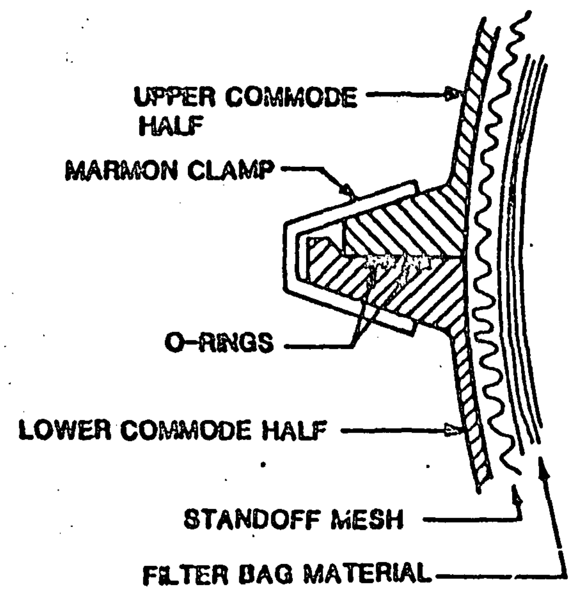
DETAILS OF A SPLIT TANK

The details of the split tank, illustrated on the facing page, are typical for the Improved WCS System Concept. The split tank design should be optimized as an output of a detailed design study that would consider tank shape, vacuum and vessel integrity, and ease of bag liner removal and replacement in relationship to flange thickness, O rings, and the clamping device.

DETAILS OF SPLIT TANK



Detail A



Detail B

IMPROVED WCS MODES OF OPERATION

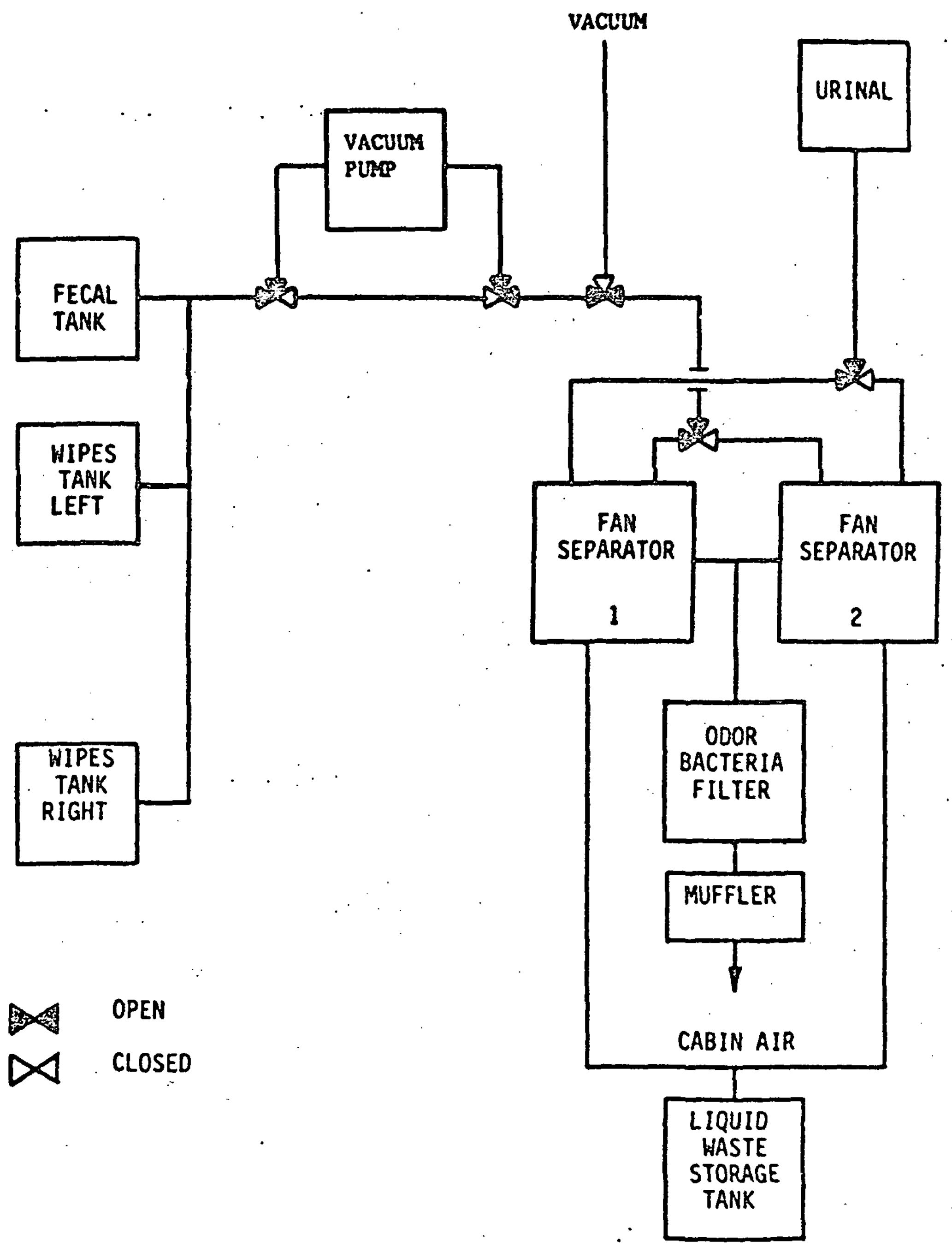
The following section discusses the modes of operation for the Improved WCS System Concept.

IMPROVED WCS MODES OF OPERATION

THREE-TANK COMPACTOR DEACTIVATED MODE

The schematic on the facing page illustrates the three-tank compactor concept configured in the deactivated mode. All tanks are closed and evacuated.

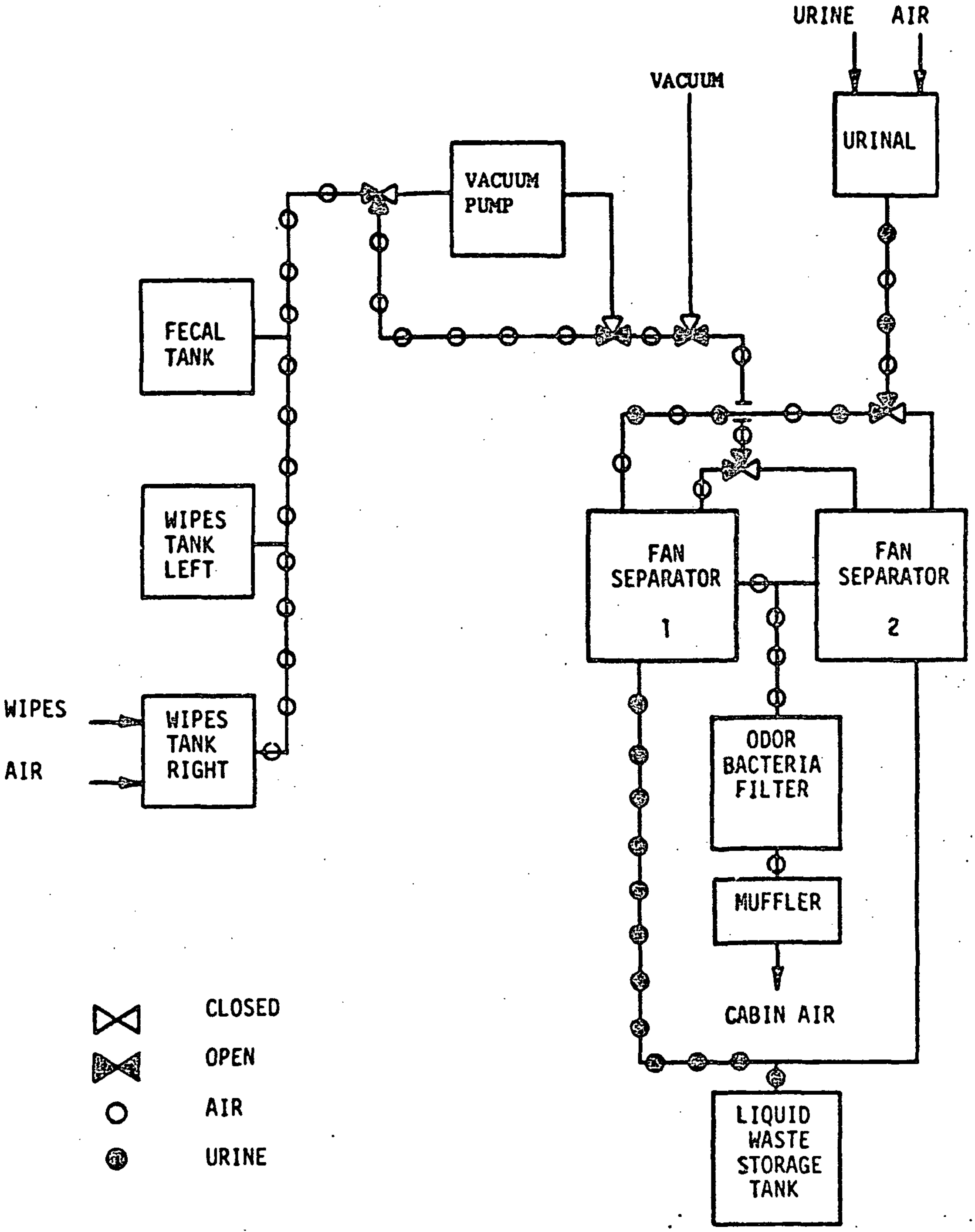
THREE TANK COMPACTOR DEACTIVATED MODE



THREE-TANK COMPACTOR - URINATION MODE

The schematic on the facing page illustrates the three-tank compactor concept configured in the urination mode. Urine and entrainment air enter the system through the urinal, and encounter either fan separator. The fan separators remove fluid from the air, and send the fluid to the liquid waste storage tank. Wipes and ballast air enter the system through either wipes tanks. Wipes are stored in the wipes tanks and the air is filtered through the bag liner. This filtered air also goes through the fan separators and joins the urine entrainment air. This air then flows through the odor/bacteria filter, the muffler, and back to the cabin. The fecal tank is closed and evacuated.

THREE TANK COMPACTOR
URINATION MODE

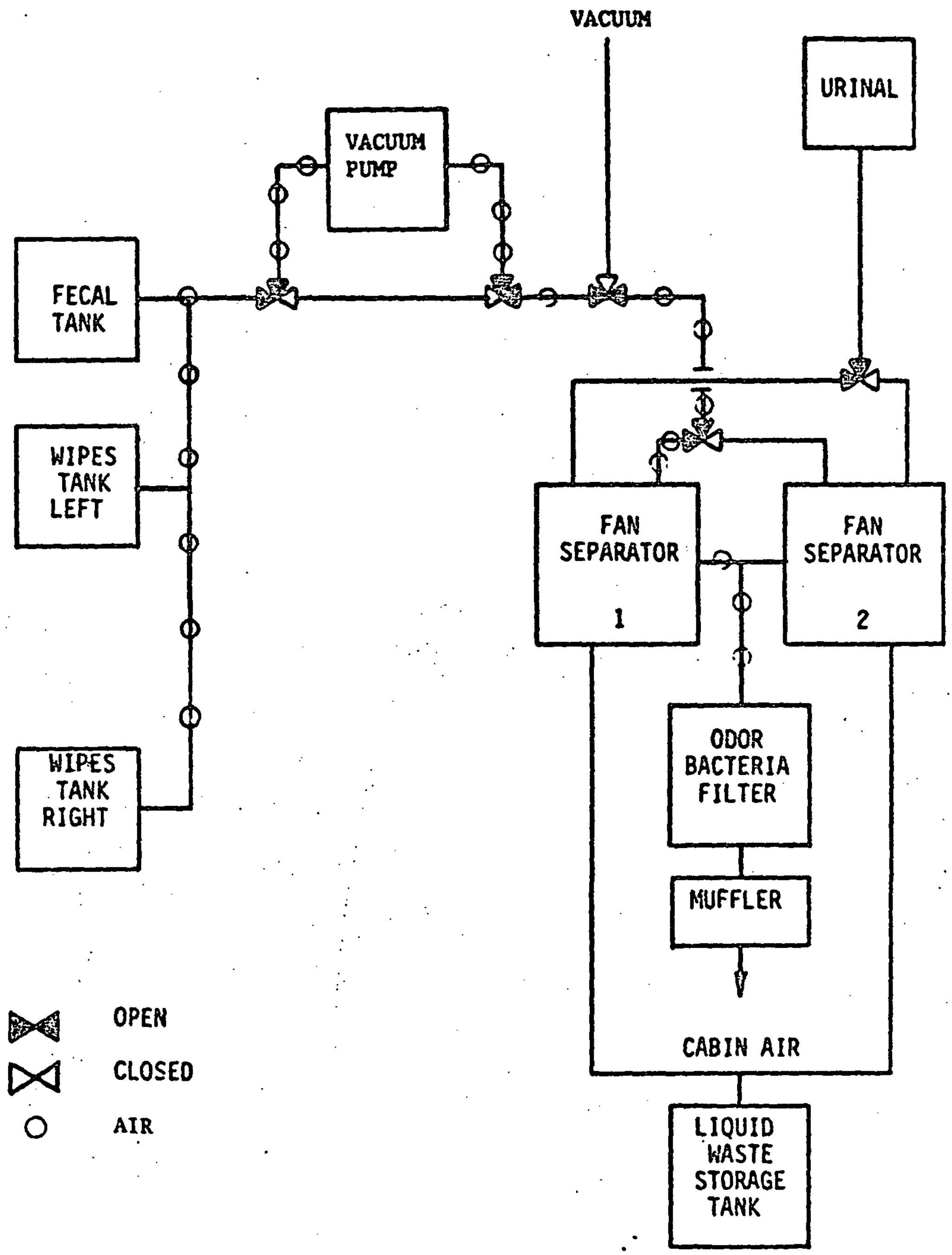


EVACUATION MODE

The schematic on the facing page illustrates the three-tank compactor concept configured in evacuation mode. Upon completion of all cleansing processes, all three tanks are closed and evacuated by the vacuum pump. In the event of a vacuum pump failure, the tanks can still be vented to space. The evacuated air flows through a fan separator, the odor/bacteria filter, the muffler, and back to the cabin. The tanks remain evacuated until the next system usage.

THREE TANK COMPACTOR

EVACUATION MODE



URINATION/DEFECATION MODE

The schematic on the facing page illustrates the three-tank compactor concept in the urination/defecation mode. Urine and entrainment air enter the system through the urinal, and encounter either fan separator. The fan separators remove the fluid from the air and send the fluid to the liquid waste storage tank. Feces and separation air enter the fecal tank, where the feces are stored in the fecal tank bag. The separation air flows to the fan separators, where it joins the urine entrainment air. The air then flows through the odor/bacteria filter, muffler, and back to the cabin. The wipes tanks are closed until the cleansing process is ready to begin, so that high air flow rates for fecal separation, are maintained through the fecal tank.

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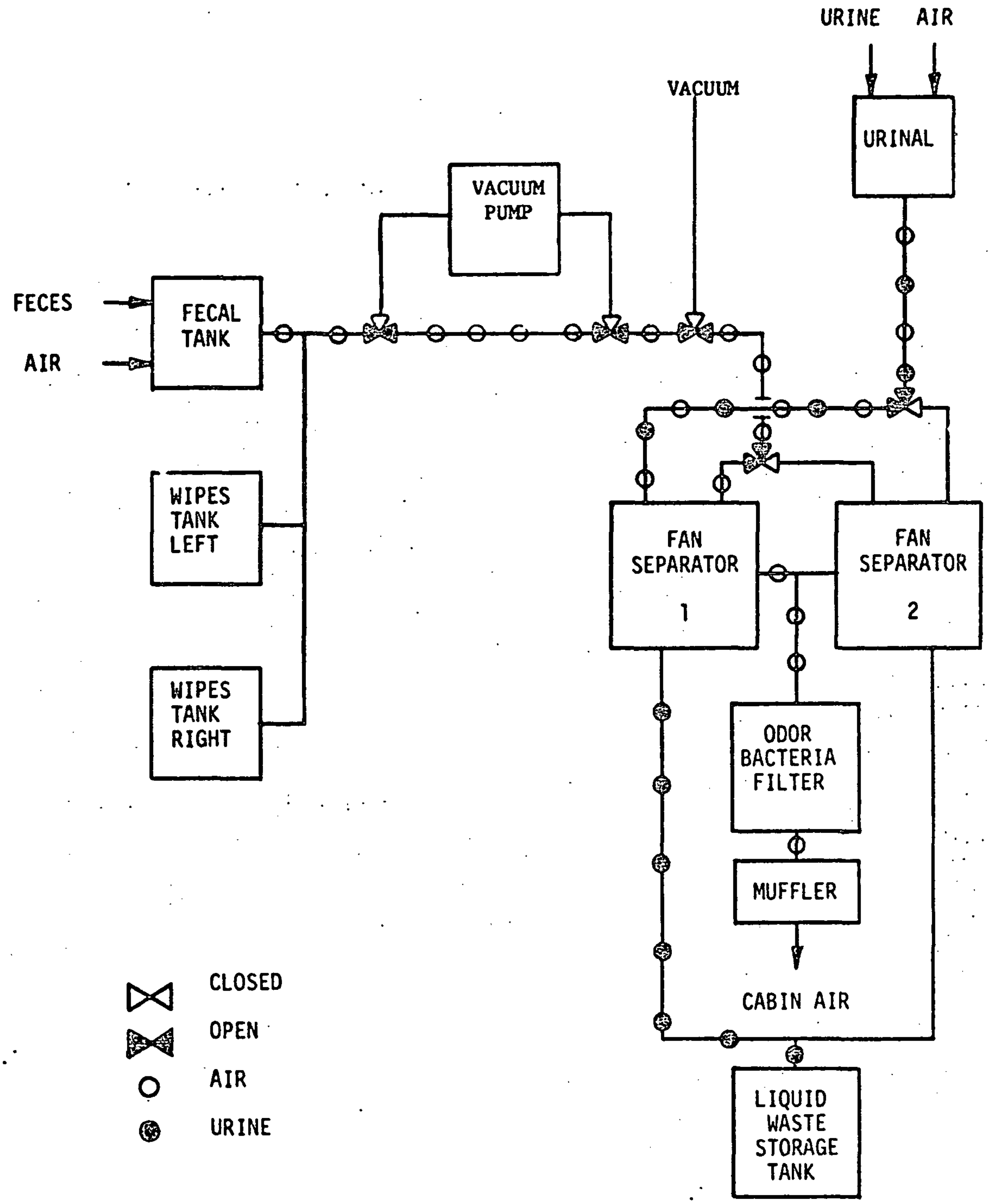
THREE TANK COMPACTOR URINATION/DEFECATION MODE

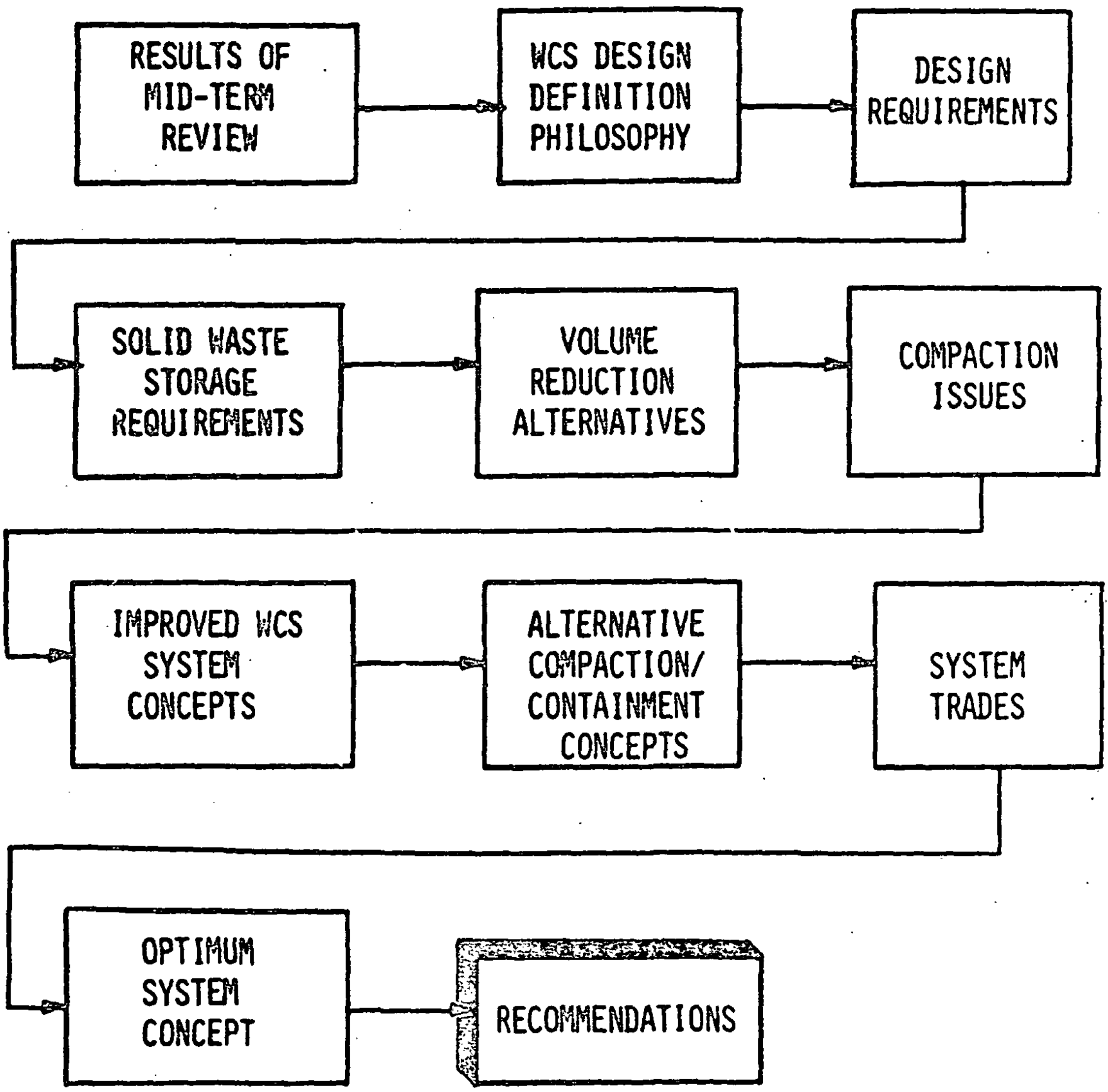
SPACE SYSTEMS DIVISION



RECOMMENDATIONS

The following section presents the conclusions and recommendations of this study.

FINAL PRESENTATION FLOW



CONCLUSIONS

The conclusions of this study are presented in this chart.

The three-tank compactor concept - the optimum Improved WCS Concept - represents a simple design, utilizing many elements of the current baseline system.

The design is in-flight serviceable thereby providing variable capacity and permitting usage for extended missions (in excess of 210 man-days) so long as stowage provisions exist for replaceable elements.

The optimum concept incorporates a vacuum pump to eliminate venting to space, satisfying known Space Station requirements, and hence, representing a viable Space Station WCS configuration.

CONCLUSIONS

- THREE TANK COMPACTOR CONCEPT IS THE OPTIMUM SYSTEM CONCEPT
- REPRESENTS A LOW RISK DESIGN APPROACH FOR UTILIZATION IN EXTENDED LIFE MISSIONS
  - SIMPLE DESIGN
  - UTILIZES MANY ELEMENTS OF CURRENT BASELINE SYSTEM
  - PROVIDES VARIABLE CAPACITY CAPABILITY AND MAINTAINABILITY OF DEGRADABLE SYSTEM ELEMENTS
- REPRESENTS A VIABLE SPACE STATION IOC WCS CONFIGURATION
  - VARIABLE EXTENDED LIFE CAPACITY
  - NO VENTING TO SPACE DURING NORMAL OPERATION

RECOMMENDED DEVELOPMENT PROCESS

The Improved WCS Concept presents NASA with the opportunity to validate and implement the concept in a stepwise manner.

1. A piston type wipes compactor should be developed, integrated with the current WCS, and flown to demonstrate the compaction function, and evaluate in-flight servicing.
2. A vacuum pump (possibly a reconfigured version of the galley compressor) should be integrated with the current WCS to demonstrate vacuum drying using this technique and evaluate potential impact on cabin humidity control.
3. Concurrent with these efforts, a detailed design definition of the Improved WCS should be conducted, optimizing the various system elements.
4. Upon successful completion of these three steps, a full-scale development of the Improved WCS should be initiated and incorporated into the Shuttle orbiter as replacement for the current design.

RECOMMENDED DEVELOPMENT PROCESS

- DETAILED DESIGN OF OPTIMUM SYSTEM CONCEPT
- DEVELOPMENT AND FLIGHT DEMONSTRATION OF WIPES COMPACTOR
- DEVELOPMENT AND FLIGHT DEMONSTRATION OF OPTIMUM SYSTEM

APPENDIX A

SYSTEM REQUIREMENTS DEFINITION DOCUMENT
FOR AN IMPROVED WASTE COLLECTION SYSTEM

TABLE OF CONTENTS

LIST OF FIGURES

SECTION 1
SCOPE

1.1 SCOPE

This document establishes the system requirements for an Improved Waste Collection Subsystem, referred to herein as the "Improved WCS."

SECIION 2
APPLICABLE DOCUMENTS

2.1 APPLICABILITY

The following documents of the exact issue form a part of this document to the extent specified herein. In the event of a conflict between the documents referenced herein and the contents of this document, the contents of this document shall take precedence.

SPECIFICATIONS

National Aeronautics and Space Administration/Johnson Space Center (NASA/JSC)

MSCM 8080 16 October 1972 Change 5	Manned Spacecraft Criteria and Standards

Rockwell International/Space Division

MC999-0096D 30 August 1974 Amendment E-01 Amendment E-02 24 January 1975 Amendment E-03 9 May 1975 Amendment E-04 (Not Applicable) 4 December 1975 Amendment E-05 6 December 1976 Amendment E-06 9 May 1977 Amendment E-07 17 June 1977 Amendment E-08 11 March 1980 Amendment E-10 17 August 1981 Amendment E-13 12 May 1982	Materials and Processes Control and Verification System for Space Shuttle Program: Suppliers and Subcontractors.
MC999-0097B 15 March 1974	Pressure Vessel, Space Shuttle Orbiter Requirements For

SPECIFICATIONS (Continued)

MF0004-002B 28 June 1974 Amendment C-01 20 March 1975 Amendment C-02 4 November 1975	Electrical Design Requirements for Electrical Equipment Utilized on the Space Shuttle Vehicle
MF0004-006A 1 March 1974 Amendment B-01 2 August 1974 Amendment B-02 3 March 1975	Instrumentation Requirements for Suppliers and Subcontractors for the Space Shuttle Program
MC282-0069 19 July 1984 Rev F	Collector Subsystem, Waste

STANDARDS

Federal

FED-STD-101B(2) 8 October 1971	Preservation, Packaging, and Packing Materials: Test Procedure

Military

MIL-STD-810B(4) 21 September 1970	Environmental Test Methods
MIL-STD-1472A 15 May 1970	Human Engineering Design Criteria for Military Systems, Equipment, and Facilities

SECTION 3
REQUIREMENTS

3.1 IMPROVED WASTE COLLECTION SUBSYSTEM (IMPROVED WCS) DEFINITION

The Improved WCS will be used for:

1. Collecting, storing, and drying fecal wastes, and associated toilet paper within the Improved WCS envelope.
2. Collecting wash water from the galley.
3. Collecting Extravehicular Mobility Unit (EMU) water from the airlock.
4. Collecting urine and urine wipes.
5. Transferring the collected fluids to waste storage tanks (not a part of this document).
6. Draining air and vapors from the wet trash storage compartment.

The Improved WCS will accommodate both male and female occupants in zero gravity and in one g with vehicle in the horizontal position. Fecal waste will not be handled by crew. Fecal waste will be dried by exposure to vacuum. Air flow will be used for separation of the feces, for directional control of the fecal waste, for odor and contamination control, and for urine entrainment during space operations. There will be no water flush in the fecal waste or urine collection systems.

3.1.1 SYSTEM DESCRIPTION

The Improved WCS utilizes the baseline WCS concept as described in MC282-0069, Rev. F, "Collector Subsystem, Waste," dated 19 July 1984 with modifications as follows:

1. The Improved WCS utilizes three containment vessels with filtration bag liners for collection and storage of feces, fecal wipes, and urine wipes. Feces and those wipes associated with separation of the final portion of each defecation are deposited in the fecal tank; all other wipes associated with the defecation cleansing process and the urination cleansing process are deposited in either of two redundant wipes tanks, which have integral vacuum or manually actuated piston-type compactors for paper volume reduction.

2. All tanks are split to provide capability for in-flight bag liner removal and replacement, and to maximize ease of post-flight servicing. The Improved WCS, therefore, becomes a variable-capacity system.

3. The bag liners are sized to provide in excess of 210 man-days storage capacity with projected normal usage and packing, requiring <u>no</u> routine in-flight service.

4. Used filtration bag liners must be stowable in non-porous containment bags with provision to eliminate the effects of any pressure changes during the mission.

5. Fan separators may be used singly or in parallel to provide the capability of starting from a flooded state or of overcoming possible drops in air flow rate.

6. A vacuum pump is incorporated, with output to the odor bacteria filter, to evacuate the waste collection tanks. This results in a "vacuum drying" of the fecal waste and wipes, reducing contaminant agents and metabolic processes for odor and contamination control.

   The vacuum pump effectively eliminates cabin air loss, and additionally, the system retains capability to evacuate to space as an alternative evacuation method.

Figure 1 is a schematic of the Improved WCS.

3.1.2 INTERFACE DEFINITION

3.1.2.1 Electrical Power Characteristics

The electrical power characteristics at the Improved WCS interface shall be in accordance with MF0004-002B.

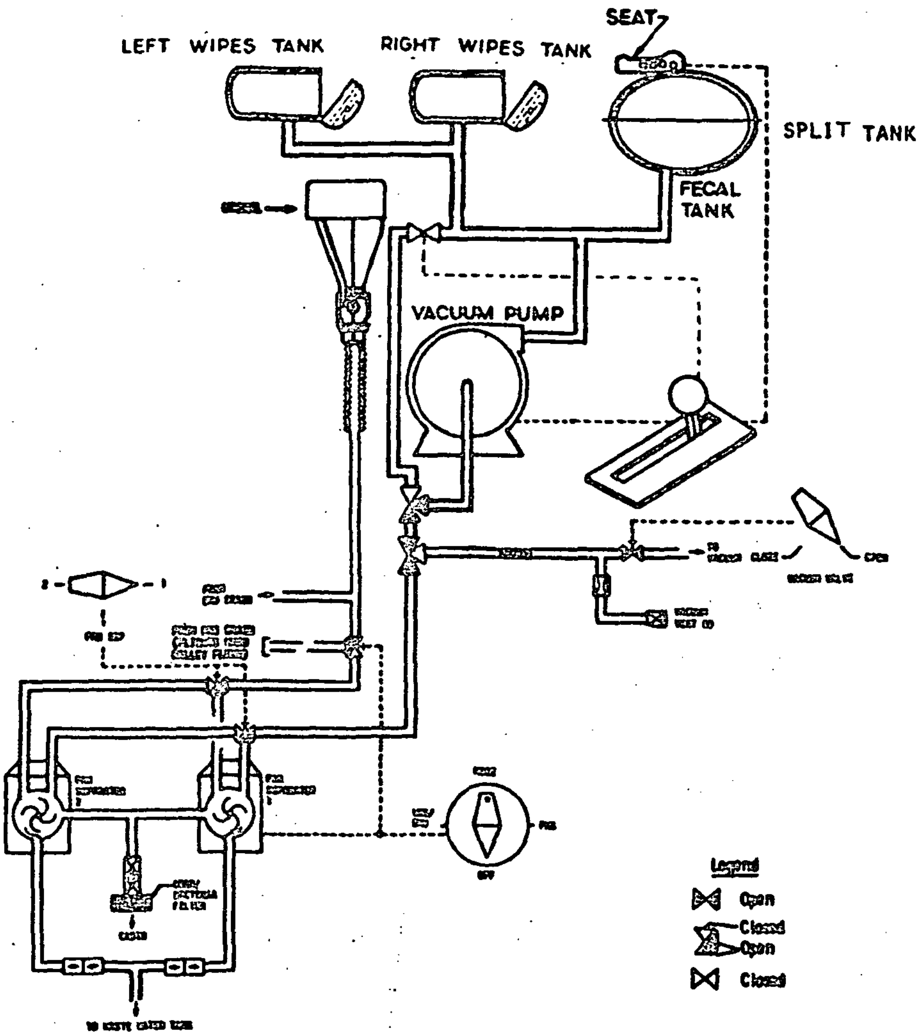


Figure 1. Improved Waste Collection System Schematic

3.1.2.2 Instrumentation

Operational instrumentation (OI) and development flight instrumentation (DFI) interfaces shall be in accordance with MF0004-006A.

3.1.2.3 Power Characteristics

The Improved WCS shall perform as specified herein with input power meeting the requirements of MF0004-002B for main dc power (28 vdc) and for inverter ac power (400 Hz, 115 vac, 3 phase).

3.1.2.4 Definition of Influents

The influents from the galley/PHS, airlock EMU, and wet trash storage shall be as shown in Tables IV, V and VI of MC282-0069, Rev. F, Dated 19 July 1984.

3.1.3 ITEM AND MAJOR COMPONENTS

The major components of the Improved WCS are as follows:

1. Waste Collection Assembly
    a. Fecal Tank Assembly
    b. Left and Right Wipes Tank with Vacuum Actuated Compactor Assemblies
    c. Fecal Tank Bag Liner
    d. Left and Right Wipes Tank Bag Liners
    e. Vacuum Actuated Piston Compactors
2. Urine Collection Assembly
    a. Male Urinal Cap
    b. Female Urinal Cap
3. Odor/Bacterial Filter
4. Muffler

5. Two Fan Separators with High Torque Motors

6. Vacuum Pump

3.2 CHARACTERISTICS

3.2.1 PERFORMANCE

3.2.1.1 Life Performance

The Improved WCS shall be designed to provide the most cost effective Life capability, considering minimum maintenance and refurbishment as well as state-of-the-art hardware design. Upon completion of tradeoffs by the seller to establish the optimal relationship between hardware life capability, maintenance, and refurbishment, the following life objective will be changed to requirements.

3.2.1.1.1 Operating Life

As a design objective, the Improved WCS static components shall be capable of performing all operations specified herein for a minimum of 20,000 hours.

3.2.1.1.2 Useful Life

As a design objective, the Improved WCS shall have a minimum useful life of 20,000 hours, which are equivalent to 100 orbital missions in a 10 year period from date of delivery. The average orbital mission will be 7 days; however, the design shall not preclude the capability to extend the orbital staytime up to 30 days with a crew of seven. Preventive maintenance, servicing, repair, and replacement of parts shall be consistent with the Seller's tradeoff results, as agreed to by the buyer.

3.2.1.1.3 Shelf Life

As a design objective, the Improved WCS shall be capable of operating in accordance with the requirements specified herein any time within a period of 10 years from date of delivery when exposed to the environment of 3.2.5.

3.2.1.2 Waste Collection Assembly

The Waste Collection Assembly shall accommodate both male and female crew members and shall contain the fecal tank assembly, the urine collector assembly, left and right wipes tanks, vacuum actuated piston type compactors fecal tank bag liner, left and right wipes tank bag liners, all control valving, instrumentation, interconnecting plumbing, and mounting framework. The Waste Collection assembly shall accommodate at least four usages per hour. The assembly shall remove bacteria, emesis, trash, urine, and fecal odors, skin, hair, and other body particles from the entrainment air before returning it to the cabin. All portions of the assembly exposed to vacuum shall be able to withstand at least 16 psia cabin pressure without damage.

3.2.1.2.1 Fecal Tank Assembly

The fecal tank assembly shall include a split containment vessel which accommodates the fecal tank bag liner. The tank shall be designed to maximize ease of inflight removal and replacement of the fecal tank bag liner. Tank configuration shall be consistent with capacity requirements as specified in Paragraph 3.2.1.2.2, Fecal Tank Bag Liner.

3.2.1.2.2 Fecal Tank Bag Liner

The fecal tank bag liner shall be capable of containing the equivalent of 210 man days of vacuum dried feces and those wipes used for separation of the final portion of each defecation. Each man-day usage results in an average of 0.27 pounds of feces which contains 0.2 pounds of moisture. To minimize the possibility of inflight bag removal and replacement, the bag liner shall be sufficient to contain this matter under nominal undisturbed packing conditions. In any event, a minimum volume of (1.75 ft^3) shall be provided.

The fecal tank bag liner shall meet the following requirements:

1. The liner shall be capable of being removed and replaced in 0g or 1g by a new liner without tearing. The design shall preclude spillage during removal and handling.

2. The liner shall be capable of filtration of contaminated air whether the bag is empty or full of wipes and feces.

3. The liner shall be capable of operating in maximum pressure of 16 psia, and surviving a minimum pressure of 10^{-10} torr.

4. The liner shall permit repressurization when depressurization has been initiated without rupture or hole generation for the duration of a 210 man-day mission.

5. The pressure drop across the liner shall not exceed 0.6 inches of water at a 30 scfm airflow rate.

6. The liner shall be capable of removing 99.99 percent of all particles 0.45 microns or larger.

7. The liner shall be capable of supporting a maximum differential pressure of at least 0.8 inches of water.

8. The liner shall be hydrophobic.

9. The seller shall provide a bag liner design capable of providing an initial airflow rate of 30 scfm with minimal air flow degradation over the 210 man-days of use.

10. The seller shall implement the bag liner requirements so as to minimize expendable costs.

3.2.1.2.3 Left and Right Wipes Tanks

The left and right wipes tanks shall include split containment vessels which accommodate the left and right wipes tanks bag liners respectively, and vacuum actuated piston compactors. Figure 2 shows a typical wipes tank with bag liner and compactor. The tanks shall be designed to maximize ease of inflight removal and replacement of the bag liners and shall allow for compaction of wipes after each tank usage. Tank configuration shall be consistent with capacity requirements as specified in Paragraph 3.2.1.2.5, Wipes Tanks Bag Liners.

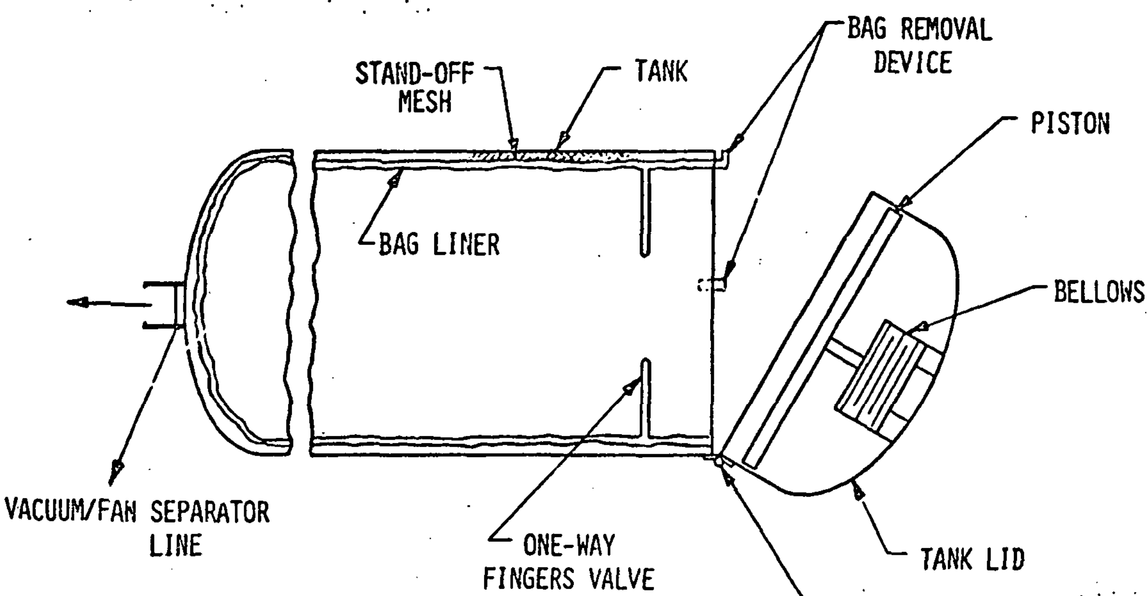


Figure 2. Typical Wipes Tank with Bag Liner and Compactor

3.2.1.2.4 Vacuum Activated Compactor

The left and right wipes tanks shall include vacuum actuated compactors which have the capability for vacuum actuated compaction of deposited wipes into the wipes tank bag liner past a one way fingers valve as specified in Figure 2. The vacuum activated compactor shall be designed with manual backup capability.

3.2.1.2.5 Wipes Tank Bag Liner

The Wipes Tank Bag liners shall be designed to maximize storage of compacted fecal clean up and urine wipes to minimize the probability of in flight bag removal and replacement. Typically, a minimum of 2.00 ft^3 volume shall be provided for total wipes tank bag liner capacity.

The left and right Wipes Tank Bag Liners shall meet the following requirements:

1. The liner shall be capable of being removed and replaced in 0g or 1g by a new liner without tearing. The design shall preclude spillage during removal and handling.
2. The liner shall be capable of filtration of contaminated air whether the bag is empty or full of compacted wipes.
3. The liner shall be capable of operating in maximum pressure of 16 psia, and surviving a minimum pressure of 10^{-10} torr.
4. The liner shall permit repressurization when depressurization has been initiated without rupture or hole generation for the duration of a 210 man-day mission.
5. The pressure drop across the liner shall not exceed 0.6 inches of water at a 30 scfm airflow rate.
6. The liner shall be capable of removing 99.99 percent of all particles 0.45 microns or larger.
7. The liner shall be capable of supporting a maximum differential pressure of at least 0.8 inches of water.
8. The liner shall have a one way fingers valve to retain compacted wipes within the liner and to enhance maintenance of air flow velocity into the bag liner.

9. The liner shall be hydrophobic.

10. The seller shall provide a liner design capable of providing an initial air flow rate of 30 scfm with minimal air flow degradation over the 210 man-days of use.

11. The seller shall implement the bag liner requirements so as to minimize expendable costs.

3.2.1.2.6 Urine Collection Assembly

The Urine Collection Assembly shall accommodate a maximum urine flow rate of 0.05 lb/second. Maximum urine quantity per mictrurition shall be 1.8 pounds.

3.2.1.3 Separator Assembly

The separator assembly shall separate the waste water from the entrainment air and shall transfer liquids to the waste water storage tanks (not a part of this document). These tanks will produce a back-pressure 12.0 psi to 20.7 psi above cabin ambient. Maximum liquid carryover to the cabin by the entrainment air shall be 0.2 percent. Average air inclusion with a liquid back pressure ranging from 12.0 psi to 20.7 psi, shall not exceed 5 percent. The separator assembly shall be able to start from a flooded state. The fan separators shall have the capability to be operated simultaneously and shall be activated prior to opening the fecal or either wipes tanks.

3.2.1.4 Vacuum Drying

The Improved WCS shall provide the capability to vacuum dry the contents of the fecal tanks and the wipes tanks in order to reduce the metabolic rates of contaminant agents, thereby minimizing bacteria reproduction, odors, and other by products.

3.2.1.4.1 Vacuum Pump Assembly

The vacuum pump assembly shall provide the primary means for vacuum drying the fecal material and the wipes. Additionally, the system shall have the capability of vacuum venting to space. The evacuation process shall not be initiable while the fan separator assembly is activated. The assembly shall allow for at least four system evacuations per hour. The assembly shall allow

for a system repressurization during evacuation so as to permit a system usage. The average cabin air loss through an empty collector due to venting and leakage shall not exceed 1.5 lbs per day when the system is evacuated to space. Pressure lines, valves, and fittings shall not exceed 10^{-4} sccs helium at 14.9 psid. Attention shall be given to minimizing the introduction of humidity to the cabin atmosphere.

3.2.1.4.2 Wet Trash Storage Ventilating

The Improved WCS shall be capable of ventilating through the wet trash storage at an air flow rate of 2.6 to 3.4 pounds per 24 hours. The wet trash storage will be ventilated from a portable trash bag through a buyer furnished fluid disconnect mounted on the front of the Improved WCS.

3.2.1.5 <u>Waste Collection Assembly Configuration</u>

Body restraints which facilitate usage of the assembly while the orbiter is performing space operations shall be provided. The body restraint system shall retain the crew person in the proper location and position for the appropriate activities. The urinal funnel assembly shall be designed for complete urine collection. Arrangement of manually controlled valves and devices and nomenclature shall facilitate operation of the assembly. It shall be possible to use the urine collector assembly and wipes tanks without activation of the fecal waste collector. Interlocks shall be provided which prevent evacuation prior to closure and sealing of the waste collector tanks. A mechanical device shall be provided to warn/prevent switching the liquid waste control switch from the "PHS/EHU" position when the EMU condensator in the airlock is being dumped. The device shall have nomenclature identifying its use. Noise dampening materials shall be applied as required to achieve the noise level requirements of Section 3.2.1.9.

The system shall be valved so as to pressurize and evacuate elements on an on demand basis. The Improved WCS shall be configured to maximize ease of defecation, wipes deposition and bag liner and odor/bacteria filter removal and replacement for in-flight and post-flight servicing.

3.2.1.6 Fecal-Emesis Collection Bags

Fecal-emesis collection bags shall be provided as a backup to the Improved WCS for fecal collection, and shall be used for emesis collection as a regular mode of operation. The fecal-emesis bags shall have a capacity of one pound. Any bags used for fecal collection shall be stored and subjected to vacuum drying in the collection assembly. Bags used for emesis collection during Improved WCS normal operation shall be stored in the wet trash storage. Wipes shall be placed in the wipes tanks.

3.2.1.7 Odor/Bacterial Filter

The odor/bacterial filter shall meet the following requirements:

1. The filter shall be capable of filtration of contaminated air from the Improved WCS at a flow rate of 38 scfm.
2. The filter shall be capable of operating in a maximum pressure of 16 psia.
3. The filter shall be capable of operation at an air flow rate of 38 scfm.
4. The pressure drop across the filter shall not exceed 2.35 inches of water at a 38 scfm air flow rate.
5. The filter shall be capable of removing 99.999 percent of all particles 0.45 microns or larger.
6. The filter shall be capable of supporting a minimum differential pressure of 1.0 psi.
7. The total weight of the filter shall not exceed 7.5 pounds.
8. The filter shall be replaceable in flight.
9. As a goal, consideration shall be given to implementing reusable elements.
10. Odor control shall be provided by the filter under projected nominal use for 210 man-days of system usage.

3.2.1.8 Urinal Caps

Individual urinal caps for male and female crew members shall be provided. The caps shall be easily installed and removed over the urinal funnel.

3.2.1.9 Muffler

The Improved WCS shall include a muffler assembly to lower noise levels created by the fan separator and vacuum pump motors to at least the noise levels specified in Section 3.3.5.

3.2.2 PHYSICAL CHARACTERISTICS

3.2.2.1 Envelope

The envelope of the Improved WCS shall not exceed the dimensions shown in Figure 3.

3.2.2.2 Mounting

Structural mounting interfaces shall coincide with existing orbiter structural hard points. The seller shall determine any desired modifications to existing mounting provisions and shall submit any changes to buyer for approval.

3.2.2.3 Weight

The weight of the Improved WCS shall not exceed 170 pounds. This weight does include expendables.

3.2.2.4 CG and Moments of Inertia

The center of gravity (CG) of the Improved WCS shall be determined in three axes from a defined referenced datum (see Figure 3).

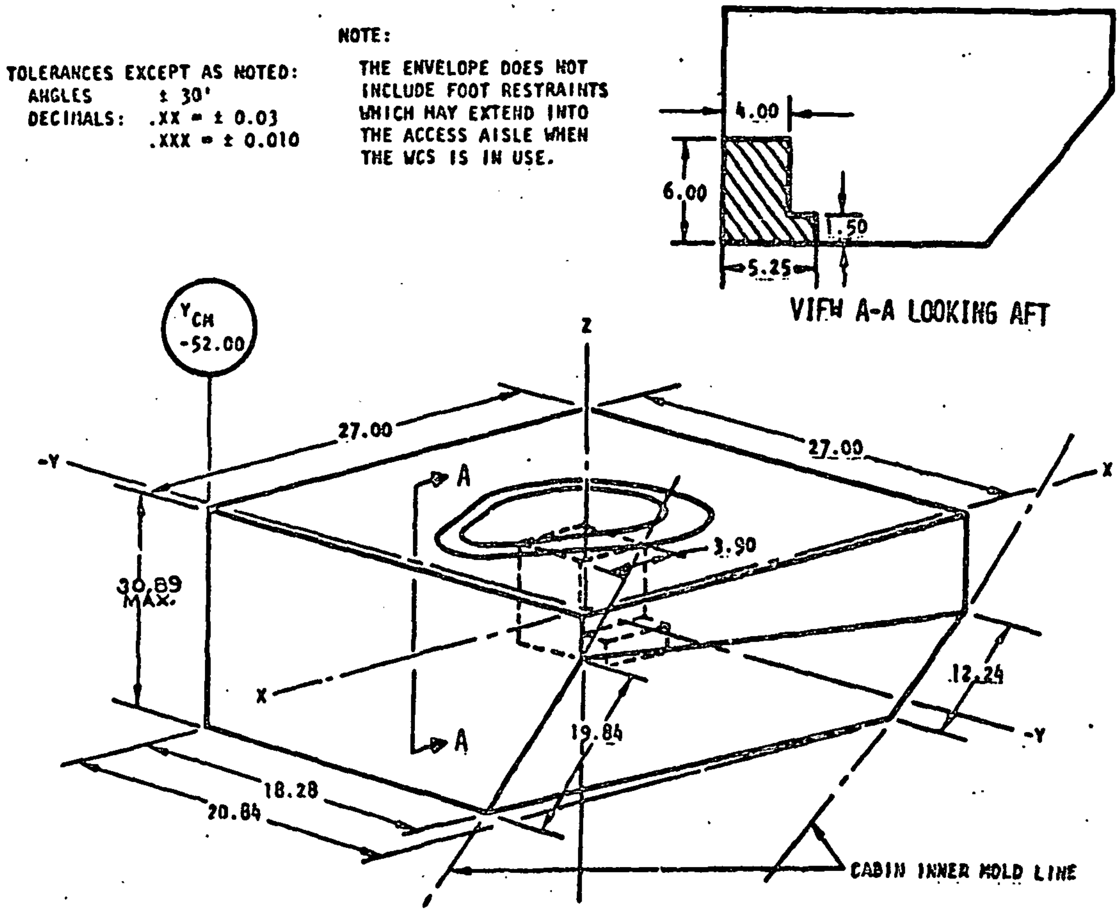


Figure 3. Improved Waste Collection System Envelope

3.2.2.5 Factors of Safety

The factors of safety specified below are minimum and shall be used for the Improved WCS components.

Components	*Proof	*Burst
Tanks, Valves	1.5	2.0
Pressurized lines and fittings less than 1.5 inch diameter	2.0	4.0
1.5 inch diameter or greater	1.5	2.0

* Note: Factors times maximum operating pressure

3.2.2.6 Pressure Vessels

Pressure vessels shall be designed to the requirements of MC999-0097B.

3.2.2.7 Monitoring Devices

Analog and discrete signals provided to the buyer monitoring devices shall be in accordance with 3.1.2.2. Motor speed indicator signals shall be provided for ground checkout only. The Improved WCS shall have as a minimum the following monitoring devices:

Absolute Pressure Transducer	0.0 to 2.0 psia; output to buyer shall be 0.0 to 5.0 volt analog
Start Switch Event	28 vdc discrete
Redundant Switch Event	28 vdc discrete
Fan/Separator and Vacuum Pump Motor Speed Indicators	Tach Signals
Fecal and Wipes Tanks Air Air Flow Indicators (3)	

3.2.2.8 Test Points

The seller shall define the test points necessary for checkout of the Improved WCS and submit to buyer for approval.

3.2.3 RELIABILITY

3.2.3.1 Redundancy

The Improved WCS shall be designed so that any single failure shall not result in:

1. Loss of Improved WCS system air flow.
2. Contamination of the cabin atmosphere.
3. Loss of the cabin atmosphere.

3.2.3.2 Failure Deterrent and Detection

The Improved WCS design shall incorporate the following:

1. Separation of Redundant Equipment

   Redundant subsystems, and redundant major elements (if used) of subsystems, panels, power supplies, tanks, controls, shall be separated by the maximum practical distance, or otherwise protected, to ensure that an unexpected event that damages one is not likely to prevent the other from performing the function.

2. Protection of Redundant Components

   To the extent practicable redundant components susceptible to similar contamination or environmental failure causes such as shock, vibration, acceleration or heat loads shall be physically orientated or separated to reduce the chance of multiple failure from the same cause(s).

3. Redundant Electrical Circuits

   Redundant electrical control circuits shall not be routed through the same connector. Redundant connectors and electrical wire bundles shall be located such that an event which damages one is not likely to damage another. Redundant components shall not be powered from the same power bus.

4. Redundancy Verification

Each path or redundant subsystem shall be capable of verification of operational status during flight. During ground turnaround, operability of all redundancies shall be capable of being verified.

5. Leak Protection - External Ports

External ports used for ground servicing shall incorporate provisions to preclude leakage in flight where such leakage could result in subsystem performance degradation. A disconnect and associated sealing cap may be considered as redundant components.

6. Check Point Connection

Electrical and fluid ground checkout test points will permit normal planned subsystem checkout to be made without disconnecting tubing or electrical connectors normally connected in flight.

7. Dead End Passages

Fluid subsystems shall not incorporate dead end passages or piping which could cause subsystem failures due to contamination buildup or corrosion.

8. Joining Techniques

Tubing and fittings shall be joined by brazing, welding or some other equivalent permanent joining technique, except where mechanical disconnects are required for replacement and servicing, or where components would be adversely affected by the joining technique.

9. Transient Caused Failures

Subsystems shall be designed such that transient out of tolerance conditions or component failures will not cause other component/subsystem failures.

10. Contamination Generation

Fluid subsystem elements shall be of a type which produces minimum contaminants which could potentially cause performance deterioration or failures by wear mechanisms or material incompatibilities.

11. Inadvertent Electrical Shorting Due to Debris

Malfunction or inadvertent operation of electrical or electronic equipment caused by exposure to conducting or non-conducting debris or foreign material flowing in a gravity free state shall be prevented by design.

12. Gravity Sensitive Components

Gravity sensitive components (i.e., lightly spring loaded check valves, scavaging type water separators, etc.) which are required to function in earth gravity, must be oriented to neutralize gravity effects in the vertical and horizontal (vehicle) modes. If hardware packaging cannot satisfy the above orientation requirement, the gravity sensitive components shall not be used.

13. Vibration Sensitive Components

Solid state switches and amplifiers shall be given preference over electromechanical relays and other vibration-sensitive electrical/electronic parts in baseline design configurations consistent with range safety requirements. Sealed-type terminal blocks shall not be used.

14. Fatigue Failures

Flexible line sections shall be designed to preclude possible fatigue failures resulting from induced vibrations.

15. Securing Threaded Parts

Threaded parts and fasteners shall be positively locked to prevent loosening during service.

16. Corrosion Control

Corrosion control shall be incorporated by the seller over the useful life of the system.

3.2.4 MAINTAINABILITY

3.2.4.1 Design Allocations

The design shall satisfy the following maintainability allocations:

1. On-orbiter fault isolation utilizing on-orbiter test capability or applicable GSE within 0.5 hours.

2. On-orbiter removal and replacement within 2.0 hours. (Assume/ensure free access).

3. On-orbiter functional checkout after removal/replacement within 0.5 hours.

4. Line Replacement Unit (LRU) off-orbiter fault isolation, Shop Replacement Unit (SRU) removal/replacement and functional checkout of each LRU to be accomplishable within 8.0 hours.

5. Scheduled maintenance required for equipment shall be limited to replacement of time/cycle sensitive equipment.

6. The odor/bacteria filter shall be in-flight replaceable within 15 minutes.

7. The seller shall define those procedures (air flow monitoring, etc.) required to determine need for on-orbit odor/bacteria filter replacement.

8. Any individual bag liners shall be replaceable in flight or post-flight within 30 minutes. Contaminated bag liners shall be placed in sealable non-porous bags valved to preclude breakage during subsequent portions of the flight through landing. These items shall be storable in areas as designated by the buyer. The seller shall define handling procedures and provide equipments (gloves, smocks, etc.) as required to preclude crew and cabin contamination.

   The seller shall maximize ease of bag liner replacement and define procedure to accomplish same with associated verification procedures to ensure system integrity subsequent to these activities.

   The seller shall define those procedures (air flow monitoring etc.) required to determine need for on-orbit bag liner replacement.

3.2.4.2 <u>Design Features</u>

The design shall incorporate the following maintainability features.

3.2.4.2.1 Maintenance

1. The Improved WCS shall be designed to nominally be maintained within the Shuttle Orbiter, and the design shall minimize maintenance requirements.

2. The Improved WCS shall be designed to preclude the use of special tools and equipment for site maintenance and repairs.

3. Special tools, if required, and approved by the buyer, shall be designed to withstand the intended use throughout the life of the equipment.

4. LRU's shall be designed so that routine corrective maintenance can be accomplished at the shop level of maintenance. Repair of LRU's shall be accomplished by the replacement of SRU's.

5. SRU's shall be designed so that maintenance actions not requiring extensive refabrication and/or refurbishment can be accomplished at the shop level of maintenance. Corrective maintenance of SRU's shall be accomplished by the replacement of minor subassemblies of piece parts. SRU's shall be designed to preclude the loss or dropping of hardware which could cause internal damage or affect the LRU's serviceability or increase maintenance time.

6. No orbiter in-flight adjustments or calibration shall be required except as identified elsewhere in this document.

7. Suitable warnings shall be provided on instruction plates or service placards if hazardous conditions exist when maintenance is performed.

8. Capability for purging/flushing of the Improved WCS shall be provided. Components which cannot be designed to satisfy this requirement shall be identified and shall use mechanical disconnect interfaces to allow local flushing or removal for flushing at an intermediate level facility. The collector assembly shall be designed for easy removal and replacement after each mission.

3.2.4.2.2 Installation

1. The equipment design shall physically prevent the incorrect installation of modules and sub-modules. Clearly visible color coding and labeling in close proximity to maintenance disconnect points shall be used to facilitate removal and replacement of any subassembly level of equipment.

2. Components shall be mounted in a manner to avoid blind adjustments.

3.2.4.2.3 Handling

1. Handling provisions shall be provided on LRU's in accordance with MIL-STD-1472A.

2. All wiring harnesses shall be protected from handling damage. The protective considerations shall not inhibit repair or replacement of the wire harness.

3.2.5 ENVIRONMENTS

3.2.5.1 Transportation (Packaged)

The Improved WCS shall be capable of meeting the operating performance requirements specified herein after exposure to the following transportation conditions when packaged in accordance with Section 5, MC282-0069, Rev F, dated 19 July 1984.

1.	Temperature	Minimum ambient of minus 65°F. Maximum ambient of plus 150°F. Maximum compartment temperature while on ground of plus 190°F for one hour and plus 150°F for six hours.
2.	Pressure	Maximum of 15.23 pounds per square inch absolute (psia) (sea level), minimum of 3.28 psia (35,000 feet).
3.	Humidity	0 to 100 percent relative humidity, including conditions wherein condensation takes place in the form of water or frost.

4.	Shock	Refer to 5.2.3, MC-282-0069, Rev. F dated 19 July 1984.
5.	Vibration	Refer to 5.2.3, MC-282-0069, Rev. F dated 19 July 1984.

3.2.5.2 <u>Storage</u>

The Improved WCS shall be capable of meeting the operating performance requirements specified herein after exposure to the following storage conditions, when packaged in accordance with Section 5, MC-282-0069, Rev. F dated 19 July 1984.

1.	Temperature	Minus 23°F to plus 150°F.
2.	Humidity	0 to 100 percent relative humidity, including conditions wherein condensation takes place in the form of water or frost.
3.	Pressure	Maximum of 15.23 psia (sea level), minimum of 9.76 psia (10,000 feet).
4.	Ozone	Surface maximum 3 to 6 parts per hundred million (phm); 60 phm for 1 to 3 hours in any 24 hour period. 100 phm at 35,000 ft.
5.	Fungus	As specified in MC999-0096D.
6.	Sand and Dust	Equivalent to 140 mesh silica flour with particle velocity up to 500 feet per minute and a particle density of 0.25 grams per cubic foot.
7.	Hail and Snow	Hail (nominal) diameter equals 0.30 inches with a fall velocity of 66 feet/second. Snow of 10.2 pounds per square foot.
8.	Salt Fog	Salt atmosphere as encountered in coastal areas, the effect of which is simulated by exposure to a 1.0 percent salt solution by weight.

9. Rain	Maximum of 19 inches in 24 hour period including short period extremes for one hour of four inches.
10. Solar Radiation	Solar radiation of 377.6 Btu/ft^2/hr for three hours in any 24 hour period.

3.2.5.3 Ground Handling Loads

The Improved WCS shall be capable of meeting the operating performance requirements specified herein after exposure to the following ground handling loads when unpackaged.

1. Handling Shock	Bench handling shock as specified in MIL-STD-810B(4), Method 516.1, Procedure V.
2. Design Shock	20 g terminal sawtooth shock pulse of a 11 millisecond duration in each of 6 axes.
3. Hoisting Loads	2 g vertical within a plus or minus cone angle of 20 degrees.

3.2.5.4 Flight Environments

3.2.5.4.1 Operating

The Improved WCS shall be capable of operating during and after being exposed to any feasible combination of environments specified in 1, 2, 3 and 4, and shall be capable of operating after being exposed to any feasible combination of environments specified in 5, 6, 7 and 8. The Improved WCS is not required to operate after being exposed to crash safety environments.

1. Temperature

Atmospheric	Minimum: 65^{o}F Maximum: 90^{o}F

C-3

	Structural	Minimum: 61°F Maximum: 120°F
2.	Pressure	
	Cabin	Maximum: 16.0 psia Minimum: 8.0 psia Rate of Chg: 1.0 psi/min Oxygen Partial Pressure Max: 3.45 psia
	Overboard Pressure	Minimum: 10^{-10} Torr
		Atmosphere Diluent - Nitrogen
3.	Relative Humidity	Maximum: 85% relative humidity at 65°F dry bulb, 17% at 90° F dry bulb
4.	Salinity	One percent by weight
5.	Lightning	As specified in MF0004-002B, Indirect
6.	Acceleration	Plus or minus 5.0 g
7.	Vibration	
	Random vibration occurs at liftoff transonic, and q max.	Acceleration spectural density increasing at the rate of plus 6 dB/octave from 20 to 150 Hz; constant at .03 g^2/Hz from 150 to 1000 Hz; decreasing at the rate of minus 6 dB/octave from 1000 to 2000 Hz. The vibration occurs for a duration of 48 minutes per axis.
	Sinusoidal Vibration results from wind gusts, engine start and shutdown, staging and landing.	Sweeps 5 to 35 Hz at one octave per minute at .25 g's peak.

8. Crash Safety

gx	gy + Right	gz + Up
+20	±3.3	+10.0 - 4.4

There shall be no failure of the mounting attachment, and the equipment shall remain in place and not create a hazard.

9. Shock

Rectangular pulses of the following peak accelerations, time durations, and numbers of applications in the vertical/up direction during landing:

Acceleration (g Peak)	Duration (Milliseconds)	Application
0.23	170	22
0.28	280	37
0.35	330	32
0.43	360	20
0.56	350	9
0.72	320	4
1.50	260	1

3.2.5.4.2 Ferry Flight

The Improved WCS shall be capable of meeting the performance requirements specified herein after exposure in a drained condition to any one or combination of the following environments.

1.	Pressure	Maximum: 15.23 psia Minimum: 3.25 psia
2.	Temperature	Maximum: Plus 120°F Minimum: Minus 10°F
3.	Humidity	Maximum: 100% Relative Minimum: 8% Relative

3.2.5.5 <u>Checkout Environment (Improved WCS)</u>

The Improved WCS shall be capable of operating as specified herein after exposure to environments specified as follows:

1. Pressure

Operational Leak Check	Cabin pressure of 18.0 psia maximum at sea level.
Structural	30 psia.

2. Temperature

Cabin	35°F minimum, 120°F maximum

3. Humidity	8 to 100% relative humidity including conditions wherein condensation takes place in the form of water or frost.
4. Salt Fog	Salt atmosphere as encountered in coastal areas, the effect of which is simulated by exposure to a 1.0% salt solution by weight.

3.2.6 TRANSPORTABILITY

The Improved WCS shall be designed so as to be capable of being handled and transported to using facilities without damage or degradation, utilizing available methods of transport with the item prepared for shipment in accordance with Section 5.1 MC-282-0069, Rev. F, dated 19 July 1984 requirements. The equipment design shall be compatible with the planned packaging and transportation system to the extent that loads induced in the equipment during transportation will not produce stresses, internal loads or deflections resulting in damage to the equipment.

3.2.6.1 <u>Disassembly</u>

Equipment requiring disassembly for shipment shall be designed to facilitate disassembly and reassembly.

3.2.6.2 Pressurization

Design shall not require pressurization of tanks or components to maintain structural integrity during shipment.

3.2.6.3 Integral Protective Capability

The equipment design shall incorporate one or more of the following provisions for protection of components which are highly vulnerable to damage during transport and associated handling:

1. Provide attach points for installation of temporary protective device (covers, reinforcing structure, desiccant cartridge, air breather/filter heater, etc.).

2. Make provisions for removal of sensitive component(s) for separate shipment.

3. Provide "built-in" protective device (e.g., cover caging of free-moving components, desiccant chamber, heater, etc.).

3.3 OTHER CONSIDERATIONS

3.3.1 FILTERS AND STRAINERS

The Improved WCS shall incorporate filters, strainers, or equivalent means to preclude deterioration of performance or malfunction due to contaminants or particle generation, entering contamination sensitive components. Where flow reversal may occur in the unit, filters or strainers shall be included on both sides of the critical contamination-sensitive components. The replaceable urine pinch valve filter shall be located upstream of a line filter in the urinal hose assembly.

3.3.2 FILTER REPLACEMENT AND CONTAMINATION

Filters shall be replaceable without requiring removal of filter housing, and shall be designed such that bacteria are prevented from escaping during filter replacement, and such that the crew is sanitarily protected.

3.3.3 ELECTROMAGNETIC COMPATIBLITY AND ELECTRICAL DESIGN

3.3.3.1 Electromagnetic Compatiblity (EMC)

The Improved WCS shall meet the electromagnetic interference and compatibility requirements of MF0004-002B for Class 1D equipment.

3.3.3.2 Electrical Design Requirements

Electrical design requirements for the Improved WCS shall be in accordance with MF0004-002B.

3.3.3.2.1 Input Power Source

The Improved WCS instrumentation shall operate from a 28 vdc power source. Rotating motors shall operate from a 115 vac or a 28 vdc power source

3.3.3.2.2 Power Consumption

The maximum power consumption of the Improved WCS shall not exceed 280 watts ac and 50 watts dc.

3.3.4 HUMAN PERFORMANCE/HUMAN ENGINEERING

The design shall consider the capabilities and limitations of the human operator wherever a man-machine interface exists, including torques, forces, and other functional design characteristics of controls, displays, and work stations. The principal design guide for the man-machine interface shall be MIL-STD-1472A.

3.3.5 ACOUSTICAL NOISE

The Improved WCS equipment shall not generate noise in excess of the following sound pressure levels (SPL) at the associated octave band center frequency (OBCF) during operation with either seat valve and/or wipes tanks open and/or closed.

Max. SPL (dB re 20μN/m^2)	OBCF (Hz)
58	63
66	125
70	250
69	500
71	1000
64	2000
64	4000
56	8000

4.0 QUALITY ASSURANCE, QUALITY CONTROL, AND PERFORMANCE REQUIREMENTS

The seller shall provide plans for quality assurance, quality control, and performance testing and validation to meet the requirements of Section 3 of this document, to the buyer to be approved prior to commencement of any manufacturing processes.

5.0 PREPARATION FOR DELIVERY

The seller shall provide plans for the preparation for shipment and the transport of the Improved WCS to all buyer and government facilities. These plans are subject to buyer approval.

APPENDIX B - OTHER ISSUES

This appendix addresses the following issues:

(1) estimate of optimum system weight

(2) bag liner/compactor details

The ability of the fan separator assembly to start from a stalled state is addressed in another study and is not considered herein, but specified as a requirement on the Improved WCS.

Investigations to establish alternatives to the current bag liner material were initiated, but remain unresolved and should be included as part of the detailed design definition.

ESTIMATE OF OPTIMUM SYSTEM WEIGHT

The estimated weight for an Improved WCS is 170.0 pounds. The weights for the system concept are rough approximations and should be finalized as an output of a detailed design study.

The elements of the estimated weight of the Improved WCS are presented in Table B-1 on the following page.

TABLE B-1

Typical System Weights (Pounds)

THREE TANKS (based on current tank thickness and material plus 20% margin)	30.0
FAN SEPARATORS (with high torque motors)	28.0
VACUUM PUMP (typical)	25.0
FILTER (from current WCS)	7.7
MUFFLER (typical)	5.5
STRUCTURE, HWD, TUBES, etc., (from current WCS)	56.0
COVER (typical)	12.0
	164.2
+ 5.8 pounds margin	5.8
	170.0 lbs

NOTE: Current WCS weight = 136.0 lbs

BAG LINER/COMPACTOR DETAIL

A cutaway of a representative wipes tank bag liner and compactor is shown in Figure B-1.

The bag liner contains a fingers valve to capture and contain wipes. Additionally, the fingers valve also reduces the effective unblocked bag liner cross sectional area, resulting in a significant increase in air velocity into the bag.

The representative compactor mechanism is a vacuum actuated piston device, utilizing a bellows with manual override.

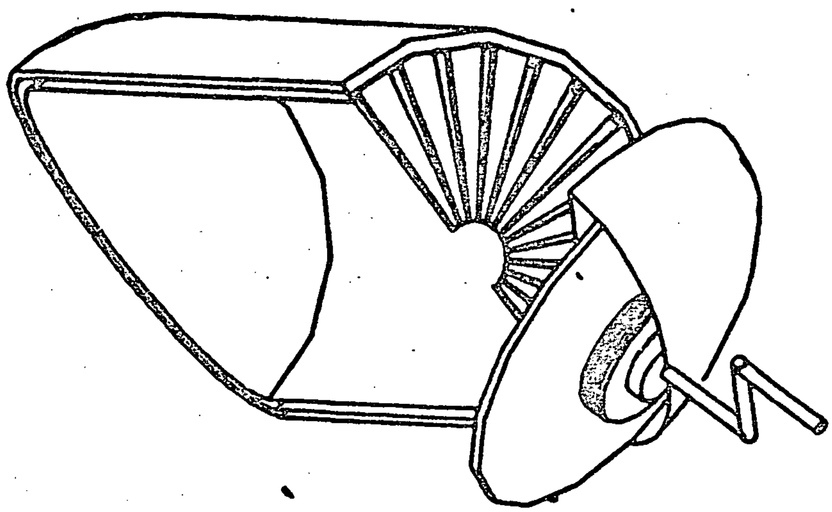


FIGURE B-1

COMPACTOR/BAG LINER DETAIL

APPENDIX C

MID-TERM STATUS REVIEW

This appendix represents the Mid-Term Status Review presentation made by the General Electric Company, to NASA on 14 September, 1984 as part of NASA Contract Number NAS9-17182.

IMPROVED WASTE COLLECTION SYSTEM STUDY

MID-TERM STATUS REVIEW

SEPTEMBER 14, 1984

IMPROVED WASTE COLLECTION SYSTEM STUDY

AGENDA

BACKGROUND/INTRODUCTION	C. OLSON
• STUDY OBJECTIVES	
• OVERALL STUDY FLOW	
• SCHEDULE	
TECHNICAL STATUS	J. FLIEGENSPAN
• REQUIREMENTS	
• LESSONS LEARNED	
• CURRENT WCS AND SUGGESTED REFINEMENTS	
• REMAINING DESIGN DEFICIENCIES	
• THE "PAPER" PROBLEM	
• WCS CONCEPTS	
• TRADE OFF CRITERIA	
• RECOMMENDED CANDIDATE CONFIGURATIONS	

BACKGROUND AND INTRODUCTION

- THE WASTE COLLECTION SUBSYSTEM (WCS) ABOARD THE SPACE SHUTTLE ORBITER HAS CONTINUED TO EXPERIENCE IN-FLIGHT USAGE PROBLEMS.

- WHILE THE URINE COLLECTION FUNCTION HAS GENERALLY WORKED SATISFACTORILY, PROBLEMS HAVE BEEN EXPERIENCED WITH FECES COLLECTION.

- THE NEED TO RESOLVE THESE PROBLEMS HAS LED TO NASA STUDIES TO ASSESS ALTERNATE CONCEPTS FOR IMPROVED WASTE COLLECTION FOR THE SPACE SHUTTLE ORBITER AND WITH CONSIDERATION FOR FUTURE SPACE STATION APPLICABILITY.

STUDY OBJECTIVES AND END PRODUCTS

OBJECTIVES

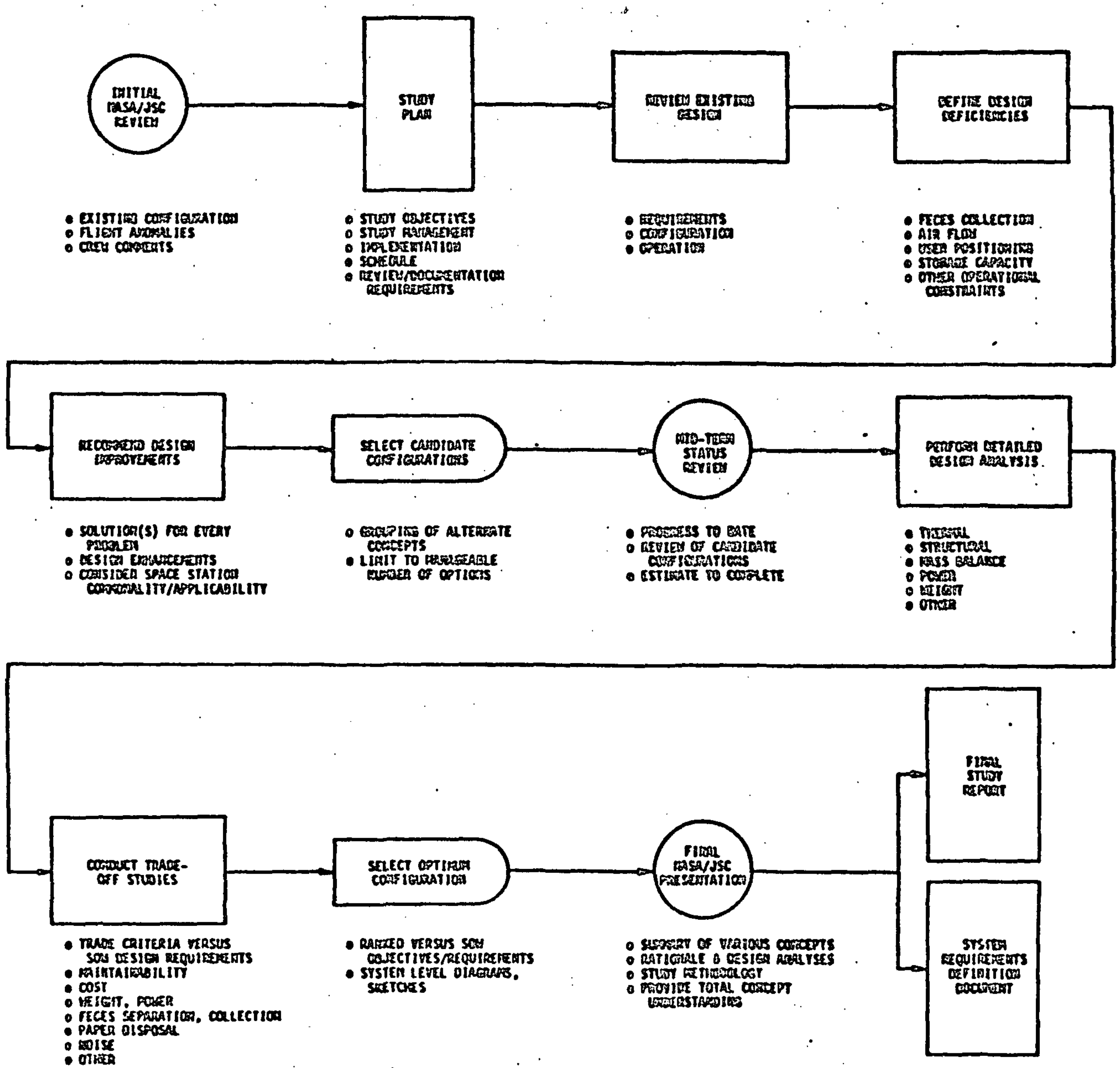
- DEVELOP A DESIGN CONCEPT FOR IMPROVED WASTE COLLECTION THAT RESOLVES IN-FLIGHT USAGE PROBLEMS FOR THE SHUTTLE ORBITER AND WHICH COULD BE A PRECURSOR FOR SPACE STATION.

- PROVIDE BASIS FOR SELECTION OF AN OPTIMUM CONCEPT WHICH COULD RESULT IN DEVELOPMENT OF AN ORBITER FLIGHT TEST ARTICLE FOR CONCEPT VERIFICATION AND SUBSEQUENT PRODUCTION OF NEW FLIGHT HARDWARE.

END PRODUCTS

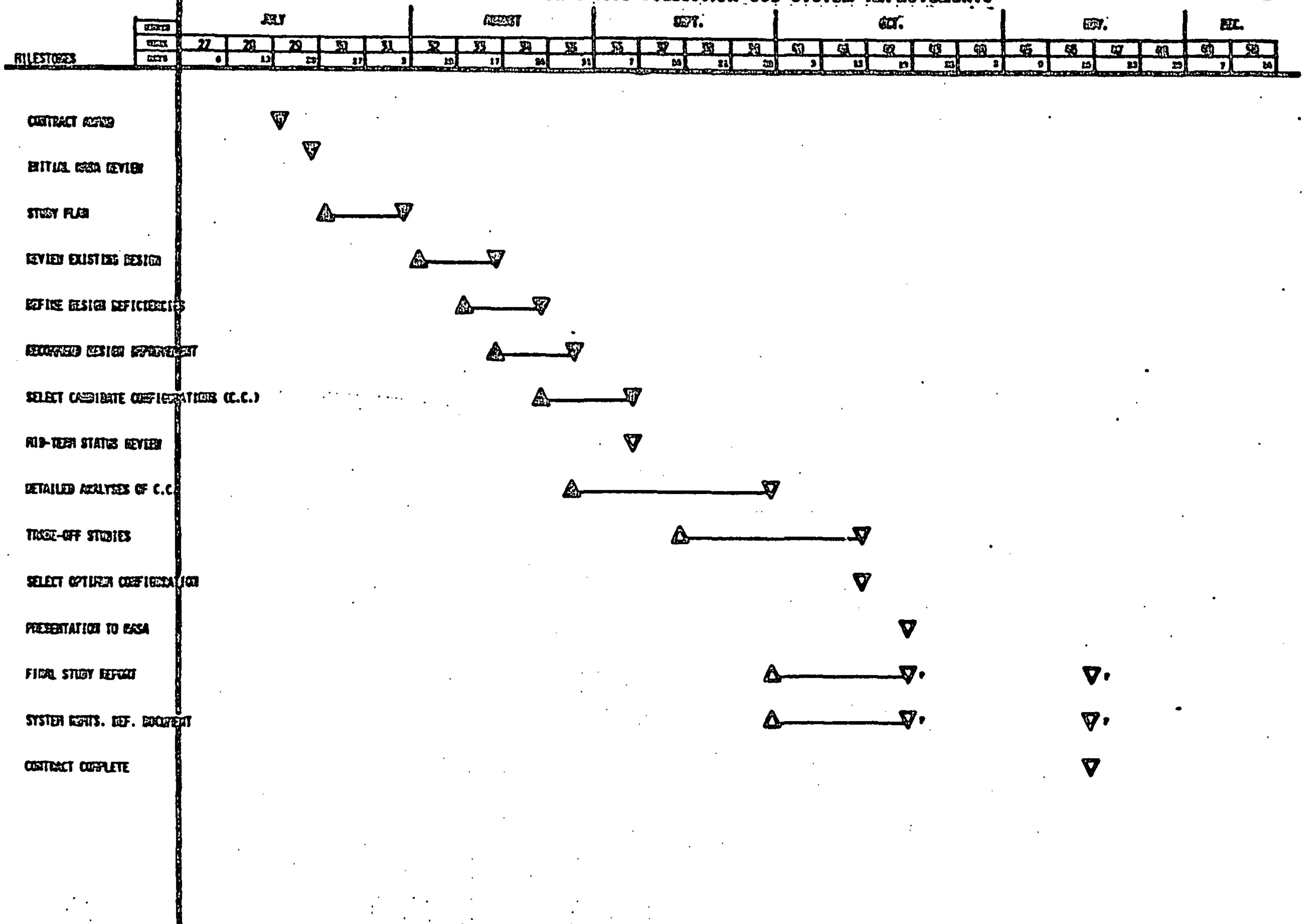
- PRESENTATION TO NASA OF A DESIGN APPROACH IN SUFFICIENT DETAIL TO PERMIT SELECTION OF AN OPTIMUM CONCEPT FOR FLIGHT TEST ARTICLE DEVELOPMENT.

- FINAL STUDY REPORT AND SYSTEM REQUIREMENTS DEFINITION DOCUMENT.



IMPROVED WCS STUDY
OVERALL WORK FLOW

DESIGN STUDY FOR WASTE COLLECTION SUB SYSTEM IMPROVEMENTS



TECHNICAL STATUS

REQUIREMENTS

PRIMARY DESIGN REQUIREMENTS

- SEPARATE WASTES FROM CREW MEMBERS:
  - EFFECTIVELY.
  - HYGIENICALLY.
- STORE THESE WASTES IN A SAFE, ODOR-LESS FORM SEPARATE FROM THE CREW COMPARTMENT.

GENERAL DESIGN REQUIREMENTS

- USABLE BY BOTH MALE AND FEMALE CREWMEMBERS.
- INDIVIDUALIZED URINE COLLECTION INTERFACE.
- TWO HUNDRED TEN MAN-DAY CAPACITY.
- EFFECTIVE, EFFICIENT STOOL SEPARATION.
- LAUNCH SITE MAINTAINABLE/SERVICEABLE.
- SIMPLE TO USE.
- MINIMAL TRAINING REQUIREMENTS.
- MINIMAL NOISE.
- RETROFITABLE WITHIN CURRENT SYSTEM COMPARTMENT.
- RELIABLE.
- MINIMAL CREW INTERFACE WITH WASTES.
- ADEQUATE BODY STABILIZATION.
- BACTERIA AND ODOR CONTROL.

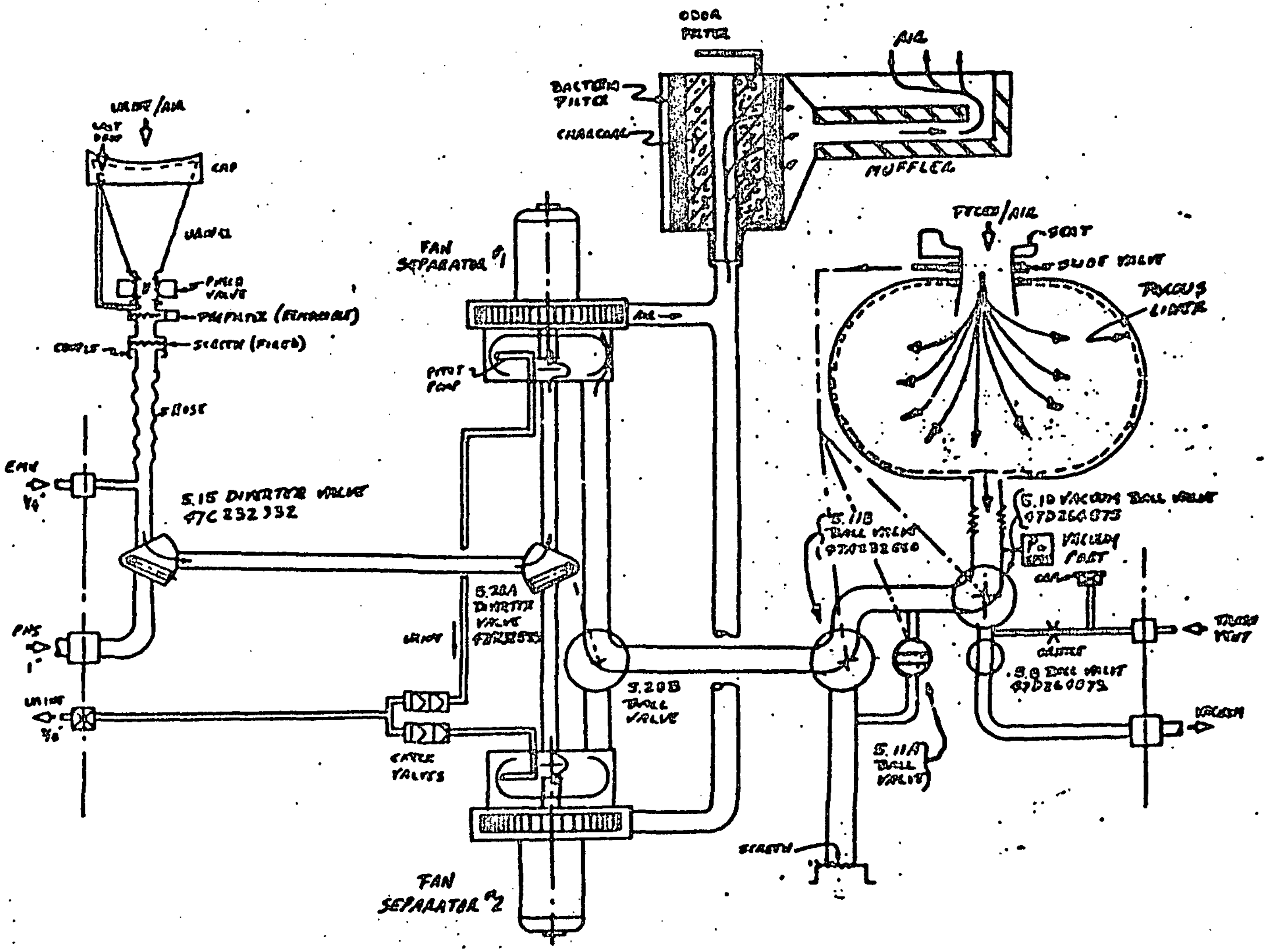
LESSONS LEARNED

LESSONS LEARNED FROM PAST EXPERIENCE

- SOLID WASTE STORAGE VOLUME NEEDS CRITICAL.
- POST FLIGHT MAINTENANCE MUST RECEIVE EARLY DESIGN ATTENTION.
- HABITABILITY FEATURES; E.G., NOISE AND EASE OF OPERATION, MUST BE PART OF THE SYSTEM DESIGN.
- SOLID WASTE FORMATION IN COMMODE IS NOT VERY PREDICTABLE.
- REFINEMENTS RESULTANT FROM IN-FLIGHT EXPERIENCE MAY BE NECESSARY TO OPTIMIZE SYSTEM.
- SHORT TERM ZERO "G" TESTS ARE INSUFFICIENT FOR TASKS REQURING LONGER TERM CREW INVOLVEMENT.
- SIMPLICITY OF DESIGN MAJOR FACTOR.
- SYSTEM MUST BE ABLE TO ACCOMMODATE WIDELY VARIANT DESIGN DRIVERS; E.G., SOLID WASTE PRODUCTION.
- PERSONAL PREFERENCES ARE WIDELY VARIANT, BUT A MAJOR DESIGN CONSIDERATION.

CURRENT WCS AND SUGGESTED DESIGN REFINEMENTS

BASELINE WASTE COLLECTION SUBSYSTEM



SUGGESTED DESIGN REFINEMENTS

- REDIRECT UNDERSEAT AIRFLOW FLOW:
    - SLOTS DIRECTING AIR BOTH UP AND DOWN.
    - SLOTS ANGLED TO DIRECT AIR IN ROTATING MOTION.
- FAN/WATER SEPARATOR MODIFICATIONS:
    - INCREASE PITOT TUBE INLET DIAMETER.
    - ADD ADDITIONAL PITOT TUBE IN EACH SEPARATOR.
- OPERATE FAN SEPARATORS SIMULTANEOUSLY TO INCREASE AIR FLOW.
- WCS ELECTRICAL MODS.
- FEMALE URINAL CAP IMPROVEMENTS FOR LAST DROP COLLECTION.
- URINAL PREFILTER AND SCREEN IMPROVEMENTS.

REMAINING DESIGN DEFICIENCIES

REMAINING DESIGN DEFICIENCIES

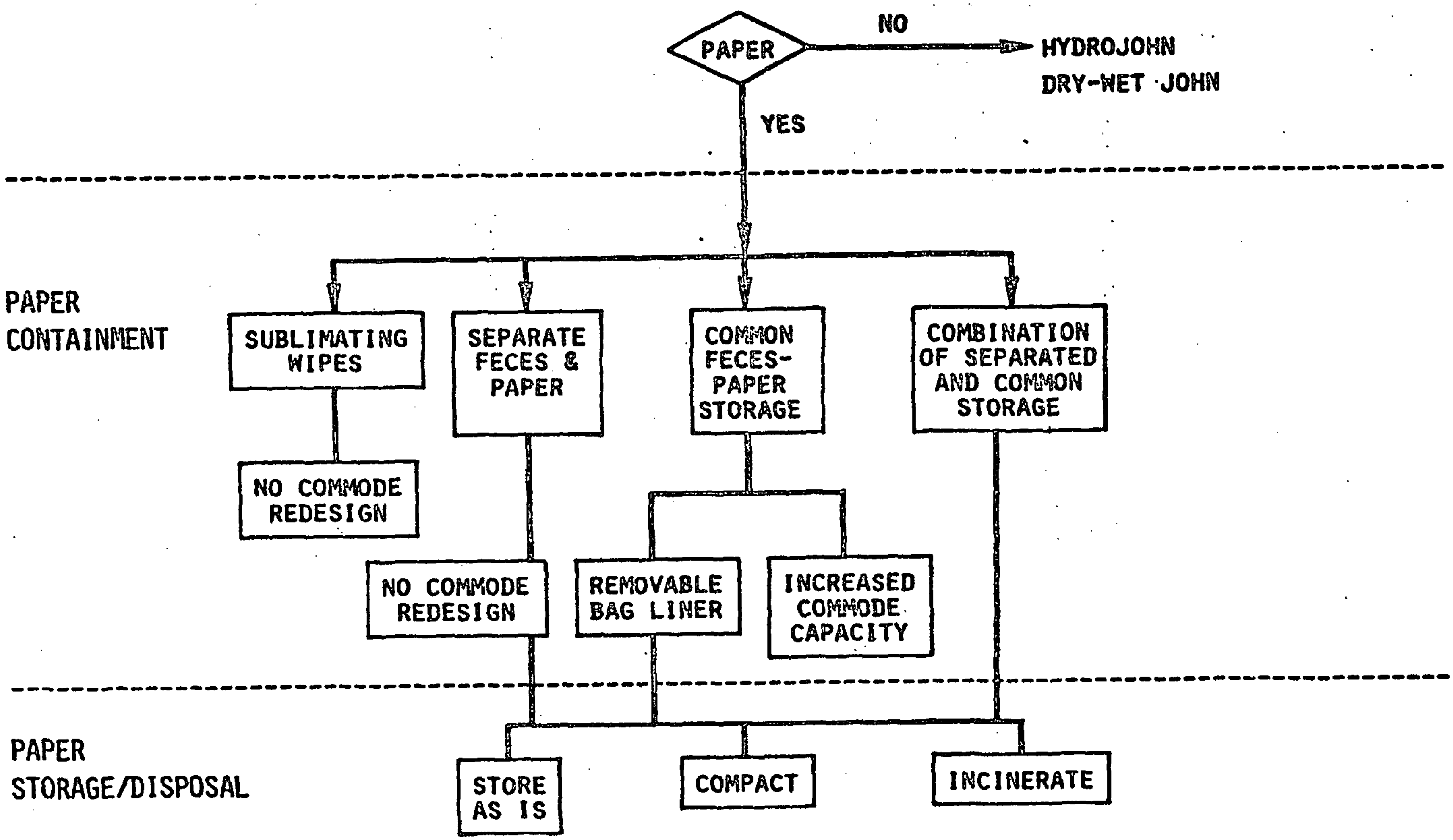
- QUESTIONABLE ABILITY TO ACCOMMODATE 210 MAN DAYS SOLID WASTE.

  (THE "PAPER" PROBLEM)

- LAUNCH SITE SERVICEABILITY IMPROVEMENT.

THE "PAPER" PROBLEM

THE PAPER PROBLEM



WCS CONCEPTS

WCS CONCEPTS

- DRY JOHN WITH SLINGER.
- DRY JOHN WITH BAG LINER (41D).
- EXTENDED LIFE DRY JOHN WITH SPLIT COMMODE (REMOVABLE BAG).
- EXTENDED LIFE DRY JOHN WITH HINGED LID TANK (REMOVABLE BAG).
- DRY JOHN WITH INTERNAL COMPACTOR.
- DRY JOHN WITH SEPARATE COMPACTOR.
- DRY JOHN WITH SUBLIMATING WIPES.
- DRY JOHN WITH REMOVABLE CONTAINER.
- HYDRO JOHN.

WCS CONCEPTS (CONTINUED)

- DRY JOHN WITH SEPARATE BAG LINER COMPACTOR.
- DRY JOHN TWO HOLER.
- ROTARY TABLE WITH BAG.
- PISTON WITH BAG.
- TURBINE.
- HYDRO DRY JOHN.
- DRY JOHN WITH INTERNAL INCINERATOR.
- DRY JOHN WITH SEPARATE INCINERATOR.
- DRY JOHN WITH LARGER CAPACITY COMMODE.
- DRY JOHN WITH SIDE COMPACTOR AND WIPER.
- DRY JOHN WITH REMOVABLE DRAWER.

TRADE OFF CRITERIA

TRADE OFF CRITERIA

- DESIGN RISK.
- DESIGN SIMPLICITY.
- COST.
- RETROFITABILITY.
- SERVICEABILITY.
- CONTINGENCY OPERATING MODES.
- NOISE.
- WEIGHT.
- POWER CONSUMPTION.
- SIMILIARITY TO "HOME" ENVIRONMENT.
- EASE OF OPERATION.
- BODY STABILIZATION.

TRADE OFF CRITERIA (CONTINUED)

- CREW INTERACTION WITH WASTES.
- SPACE STATION GROWTH POTENTIAL.
- FECES SEPARATION.
- WASTE COLLECTION.
- WASTE CONTAINMENT.
- WASTE DISPOSAL.
- BACTERIA AND ODOR CONTROL.
- WASTE RECYCLING CAPABILITY.
- TRAINING REQUIREMENTS.
- CABIN CONTAMINABILITY.
- EXPENDABLES CONSUMPTION.

CANDIDATE CONFIGURATIONS

CANDIDATE CONFIGURATIONS

- EXTENDED LIFE DRY JOHN WITH SPLIT COMMODE.
- EXTENDED LIFE DRY JOHN WITH HINGED LID TANK.
- DRY JOHN WITH SEPARATE COMPACTOR.
- DRY JOHN WITH SUBLIMATING WIPES.
- DRY JOHN WITH SEPARATE BAG LINER COMPACTOR.

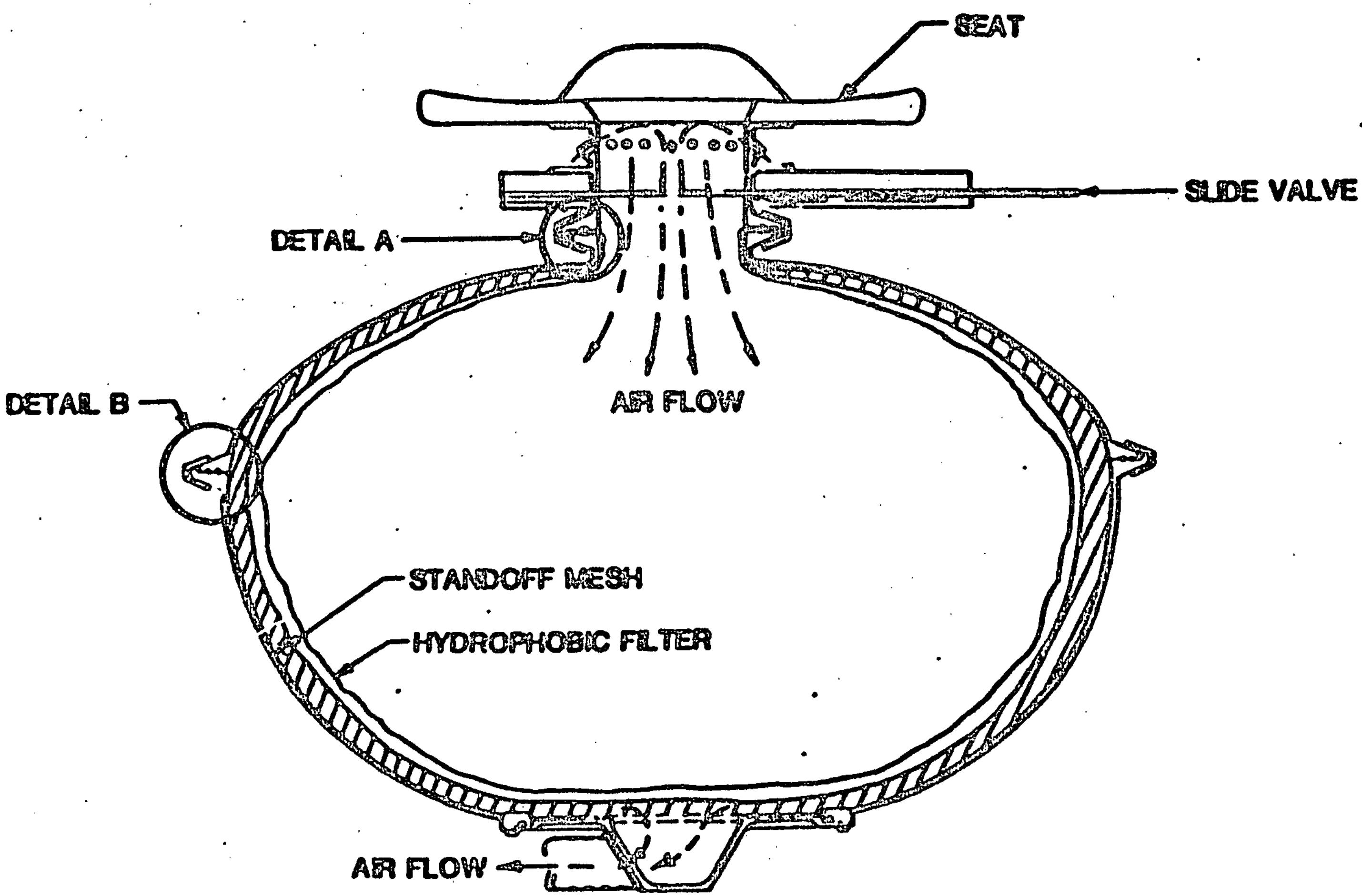
OTHERS ELIMINATED BECAUSE:

- FIXED CAPACITY SYSTEM.
- DESIGN RISK TOO HIGH.
- DESIGN UNNECESSARILY COMPLEX.

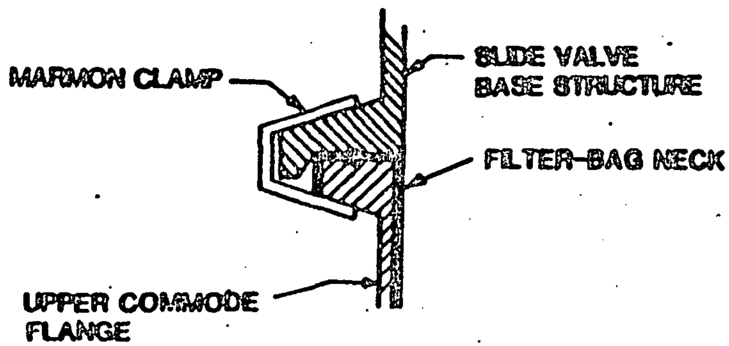
ALL CANDIDATE CONFIGURATIONS REPRESENT:

- LOW RISK DESIGN VARIANTS FROM CURRENT SYSTEM.
- SIMPLE CONFIGURATIONS.
- COULD BE UTILIZED FOR SPACE STATION IOC CONFIGURATION.
- COULD REMAIN AS BACKUP WCS FOR SPACE STATION UNTIL ALTERNATE CONCEPT IS DEMONSTRATED.

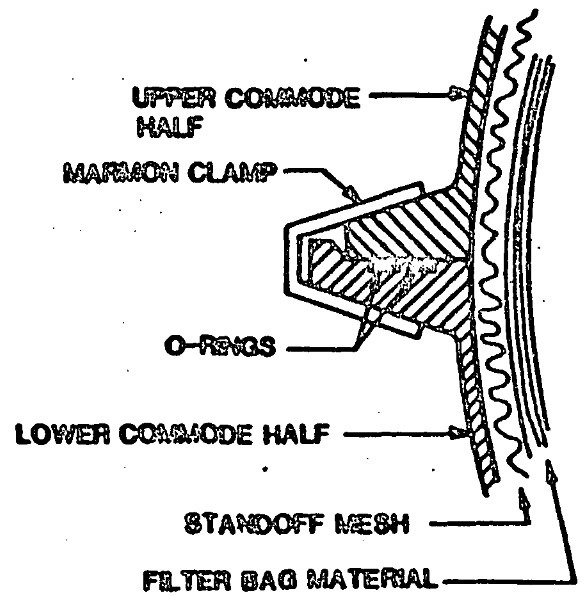
SPLIT TANK CONCEPT



DETAILS OF SPLIT TANK

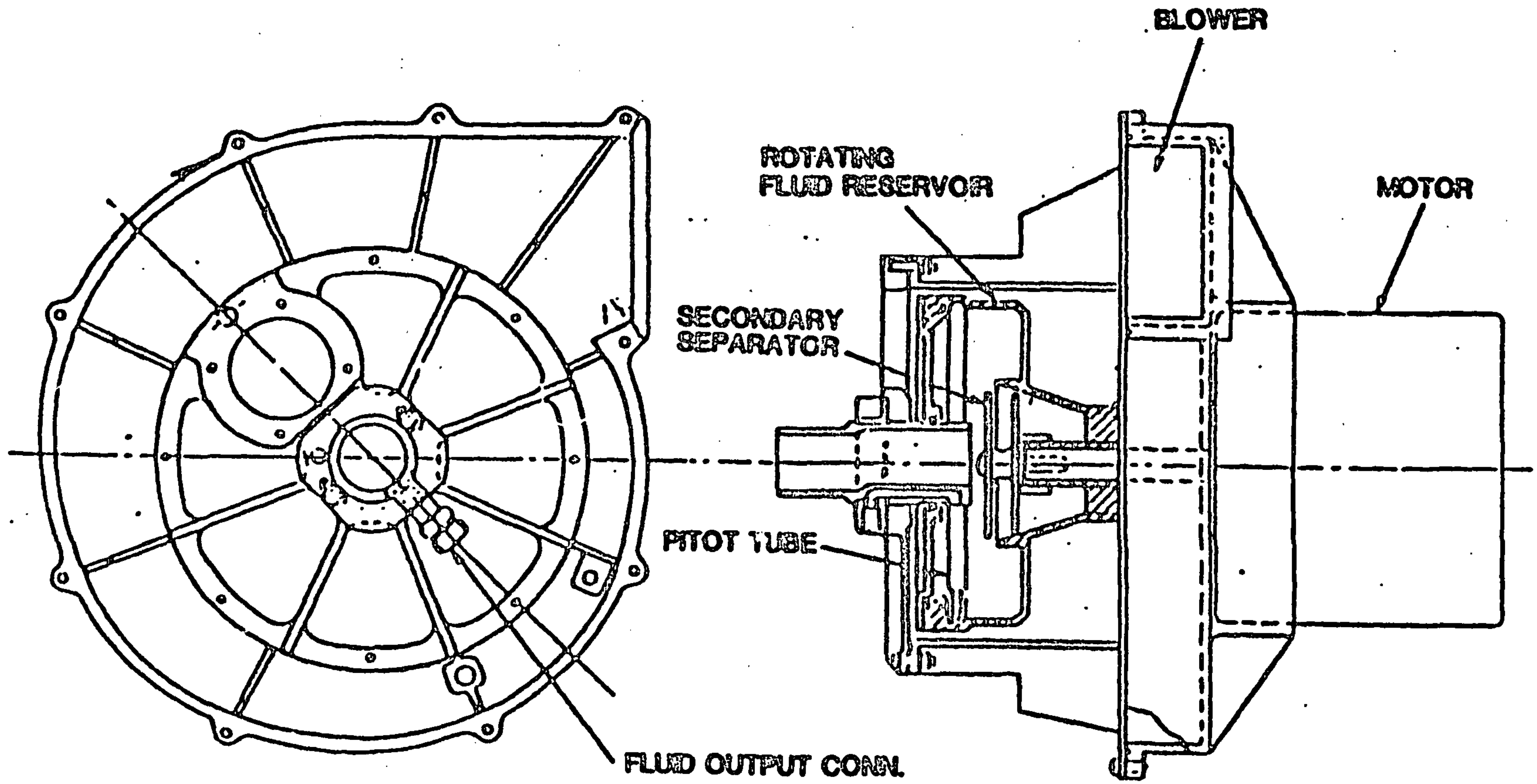


Detail A

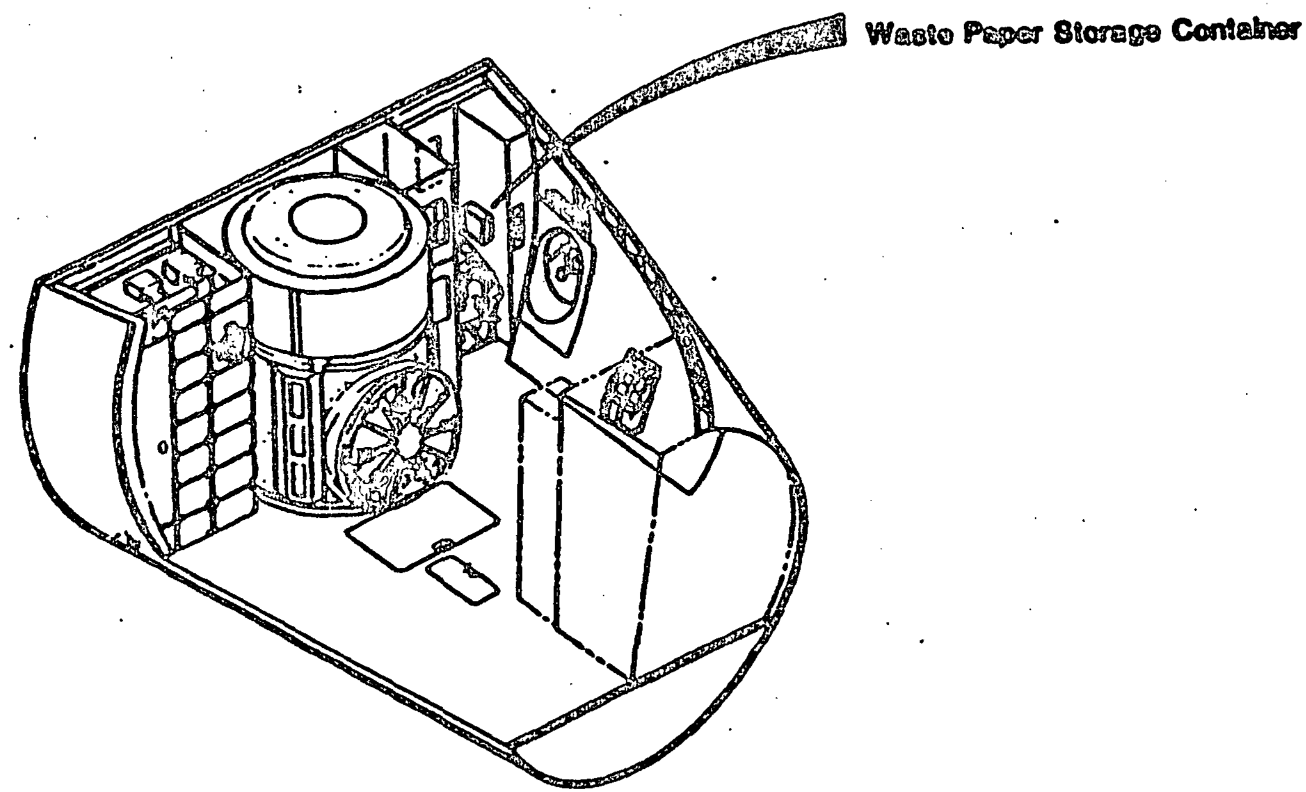


Detail B

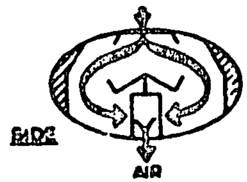
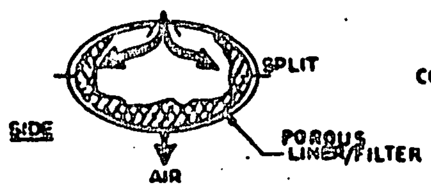
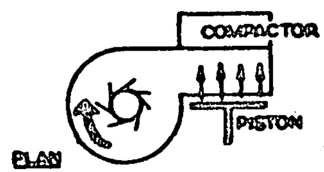
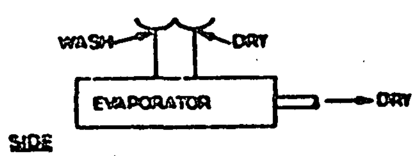
FAN SEPARATOR ASSEMBLY



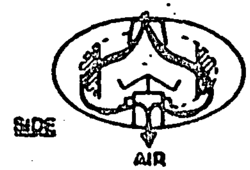
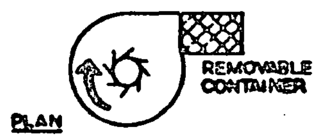
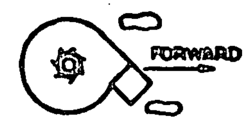
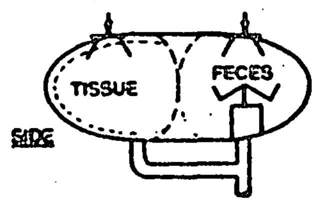
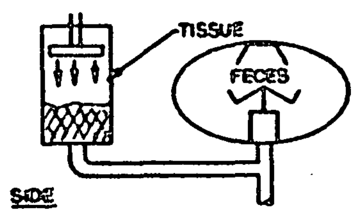
SEPARATE PAPER STORAGE CONCEPT



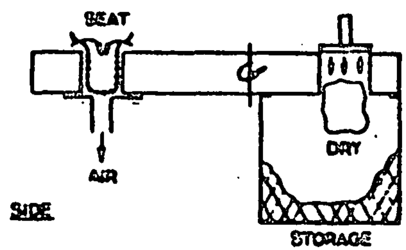
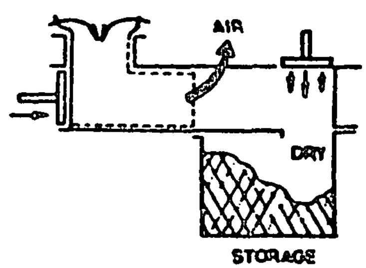
CONCEPT OPTIONS

TYPE	DESIGN/CONCEPT	STATUS	PROS/CONS	SHUTTLE COMPATIBLE	STATION OPTIONS	SHUTTLE SERVICING
DRY JOHN		FLIGHT	+ FLIGHT PROVEN – DUSTING – TISSUE VOLUME	FLIGHT UNIT	CHANGE-OUT UNIT OR COMMODE ONLY	• VACUUM • REMOVE
EXTENDED LIFE DRY-JOHN W/LINER		CONCEPT	+ WASTES RETAINED – HEAVIER PRESSURE VESSEL, SPLIT HOUSING + DELETES MOTOR AND FILTER – LINER RETENTION	+ EXTERNAL CONFIG. NOT CHANGED	BAG RETURNED	• REMOVABLE BAG
DRY-JOHN W/COMPACTOR		CONCEPT	+ WASTE NOT RECIRCULATED – MORE SEALS – MORE MECHANISM + SPACE STATION APPLICATION + HANDLE TRASH, ETC.	LAY OUT REQUIRED APPEARS FEASIBLE	LO VOLUME CONTAINER CHANGE-OUT	• REMOVABLE CONTAINER
HYDRO-JOHN		PROTOTYPES	+ NO TISSUE + URINE W/FECES + WATER EVAP. TO SPACE + INTEGRATABLE WITH TOTAL WASTE MGT. SYSTEM – MORE INTERFACES – USER ACCEPTABILITY AT FIRST LOW	+ SMALL PHYSICAL VOLUME	INTEGRATE W/INCINERATOR NO LOGISTICS SUPPORT REQUIRED	• FLUSH OUT

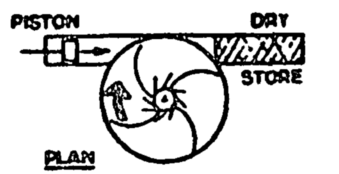
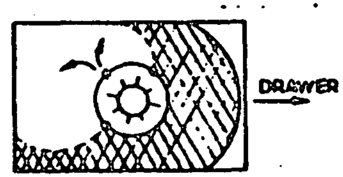
CONCEPT OPTIONS (CONTINUED)

TYPE	DESIGN/CONCEPT	STATUS	PROS/CONS	SHUTTLE COMPATIBLE	STATION OPTIONS	SHUTTLE SERVICING
DRY-JOHN		CONCEPT	+ + SLINGER BOOSTS FLOW + WASTES HELD TO WALL – SCREEN CLOGGING – REDUCED VOLUME	+ NO EXTERNAL CHANGES	CHANGE-OUT UNIT OR COMMODE ONLY	• MORE DIFFICULT
DRY-JOHN W/CONTAINER		CONCEPT	+ WASTES NOT RE-CIRCULATED – MORE SEALS		HI VOLUME CONTAINER CHANGE-OUT	• REMOVABLE CONTAINER
DRY-JOHN TWO HOLER		CONCEPT	– – TISSUE IN WRONG HOLE – LARGER PRESSURE VESSEL – MORE SEALS	– EXTREMELY DIFFICULT TO FIT IN ENVELOPE	CHANGE-OUT UNIT OR COMMODE	• VACUUM OUT • REMOVE
DRY-JOHN SEPARATE COMPACTOR		CONCEPT	– – TISSUE IN WRONG HOLE – TWO PRESSURE VESSELS – MORE SEALS – MORE MECHANISM + HANDLE TRASH, ETC.	+ FLEXIBLE ARRANGEMENT	CHANGE OUT COMMODE AND TRASH CONTAINER	• VACUUM OUT • REMOVE • REMOVE COMPACTOR

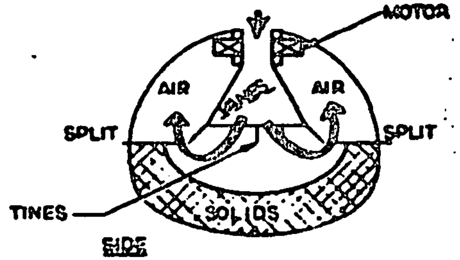
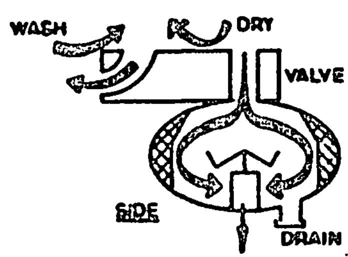
CONCEPT OPTIONS (CONTINUED)

TYPE	DESIGN/CONCEPT	STATUS	PROS/CONS	SHUTTLE COMPATIBLE	STATION OPTIONS	SHUTTLE SERVICING
ROTARY TABLE W/BAG		CONCEPT	+ + INTEGRAL SEAT/BAG + TISSUE STORE IN BAG – MORE EXPENDABLES – MORE SEALS – MORE MECHANISM + SANITARY + AUTOMATE BAG	– DIFFICULT TO FIT IN ENVELOPE	BAG RESUPPLY WASTE CONTAINER RETURN	• REMOVABLE CONTAINER
PISTON W/BAG		CONCEPT	+ + INTEGRAL SEAT/BAG + TISSUE STORE IN BAG – MORE EXPENDABLES – MORE SEALS – MORE MECHANISMS + SANITARY	+ CONFIGURATION IS FLEXIBLE	BAG RESUPPLY WASTE CONTAINER RETURN	• REMOVABLE CONTAINER

CONCEPT OPTIONS (CONTINUED)

TYPE	DESIGN/CONCEPT	STATUS	PROS/CONS	SHUTTLE COMPATIBLE	STATION OPTIONS	SHUTTLE SERVICING
DRY-JOHN W/ SIDE COMPACTOR AND WIPER		CONCEPT	+ WASTE NOT RE-CIRCULATED - MORE SEALS - MORE MECHANISM	+ SMALL PHYSICAL VOLUME	WASTE CONTAINER RETURN	• REMOVABLE CONTAINER
DRY-JOHN REMOVABLE DRAWER		CONCEPT	+ WASTE NOT RE-CIRCULATED - MORE SEALS - MORE MECHANISM	- SHAPE OF WCS AREA MAKE DRAWER REMOVAL DIFFICULT	DRAWER RETURN	• REMOVABLE CONTAINER

CONCEPTS OPTIONS (CONTINUED)

TYPE	DESIGN/CONCEPT	STATUS	PROS/CONS	SHUTTLE COMPATIBLE	STATION OPTIONS	SHUTTLE SERVICING
TURBINE		CONCEPT	+ TINES USED ONLY TO BLOCK SOLIDS + TURBINE AIDS TRANSPORT AND FLOW	+ EXTERNAL CONFIG. NOT CHANGED SIGNIFICANTLY	CHANGE OUT OR POSSIBLY SPLIT TO REMOVE BOTTOM	• VACUUM OUT • REMOVE
HYDRO-DRY JOHN		CONCEPT	+ NO TISSUE – WATER AND AIR HEATER REQ'D – WATER INTERFACE REQ'D + FLUSH DUMP WITH URINE TO STORAGE TANKS – MUST LIMIT AIR/LIQUID MIXES FLOW TO FAN SEPARATOR TO ≈ 15 CFM OR ADD VORTEX SEPARATOR – USER ACCEPTANCE LOW AT FIRST	+ SMALL PHYSICAL VOLUME	+ SMALL STORAGE VOLUME	• FLUSH OUT

APPENDIX D

EAGLE ENGINEERING MID-TERM REPORT

This appendix represents the mid-term report, "Improved Waste Collection Subsystem Concept Definition", as submitted by Eagle Engineering, Inc. to the General Electric Company, under Contract Number TO-84-77, as part of the effort under NASA Contract Number NAS9-17182.

GE Improved Waste Collection Subsystem Concept Definition

EAGLE
ENGINEERING, INC.

MIDTERM REPORT
CONTRACT NO. TO-84-77
SEPTEMBER 1984

GE IMPROVED WASTE COLLECTION SUBSYSTEM

CONCEPT DEFINITION

MIDTERM REPORT

SEPTEMBER 1984

EAGLE ENGINEERING, INC.

CONTRACT NO. TO-84-77

TABLE OF CONTENTS

1. INTRODUCTION

In-flight use of the existing Waste Collection System (WCS) aboard the Space Shuttle Orbiter has experienced some problems. The WCS is designed to accommodate both male and female crew members. Air flow is used to separate, transport, and collect the metabolic wastes, urine and feces.

Generally, urine collection has been satisfactory, especially for males. The collected urine is transferred to a waste water storage tank until it is vacuum dried.

Most of the problems experienced have been with feces collection. The feces collection assembly has undergone a series of modifications from its initial design. It contains a high speed motor which slings the feces to adhere against the side of the WCS container. After each use, the feces in the WCS is vacuum dried.

This report presents the results of the Eagle Engineering study to assess the problems experienced with the current WCS design and to suggest possible improvements to the existing WCS or to propose alternate WCS concepts for subsequent trade-off studies by General Electric (GE). This study examines the operational problems with the existing WCS, suggests possible design and operational changes to this system and presents concepts for the GE trade-off studies.

Possible design changes were previously identified in a design audit for General Electric by Eagle Engineering, Inc. (EEI) in 1983. The operational problems are recounted here and updated based on information derived from STS flights since the initial audit. The possible improvements noted in the original design audit were for near term changes and were constrained to those capable of implementation before STS-11. Design and operational changes detailed in this report are not constrained by an implementation deadline. Instead, the constraints include cost, desirability to use qualified hardware, servicability, weight, required space, and other factors to which trade studies can be applied.

The design requirements for the WCS include:

- Designed such that the crew person should not have to handle own wastes - precluded usage of bags
- Compatible for use by both males and females
- System usage should be straight forward and not take excessive time - similar to conventional household toilet

- o System should aid in stool separation during use
- o Expendables, weight, volume, and cost should be minimized
- o Design should include provisions for bacteria and odor control
- o System should accommodate 210 man-days of usage

An issue may be whether the system capacity of 210 man-days is still a valid requirement. In any event, the existing system is deficient in this area.

The GE Contract (NAS-9-17182) Statement of Work provides a concise set of general requirements. The requirements therein given are goal oriented instead of stating performance figures which must be met. The referenced Appendix C document is more specific but it stops short of providing absolute performance requirements. A statement of specific performance requirements with tolerances would be of benefit for certifying a redesigned system.

2. DESIGN AUDIT

A thorough review of the WCS design and the crew comments from the STS-1 through STS-13 flights has identified several areas that are considered weak or marginal in terms of design or performance. There are some single point failure modes and malfunction sequences.

The present WCS design may be or become a workable concept, but it is an unforgiving system. Without careful adherence tc operating instructions and scheduled programmed service, it is likely to become overloaded, resulting in user dissatisfaction and degradation or failure of its design function.

The areas of deficiencies have been separated into mechanical, electrical and operational and training deficiencies.

2.1 MECHANICAL DEFICIENCIES

Any proposed concept should benefit from the difficulties encountered with various configurations of the WCS aboard the Shuttle Orbiter. The following problems have been identified as mechanical system problems:

- Slinger slowdown and stalling
- Waste escaping from the commode
- Erratic and/or degraded air flow
- Feces collection on transport tube
- Noisy system
- Limited commode capacity
- Residual urine (female) requiring use of wipes
- Valve leakage

Several of these are interrelated. For example, tissue in the commode may cause in slinger slowdown and stalling, tissue hangup on the tines of the slinger blows dust out of transport tube in a fan action, tines striking dried fecal material knock particles out into the cabin atmosphere, dusting of fecal material clogs filters, etc.

Analysis of the system and the reported anomalies resulted in six key areas being identified where design deficiencies exist: slinger, air flow, noise, capacity, residual urine and single point failure modes.

2.1.1 Slinger Deficiencies

Several flight crews have reported that the rotational speed of the slinger motor is not constant, on occasion it has stopped completely, and at other times fecal material and dust have been ejected from the commode. To cure the rotational speed problem, a direct drive higher RPM motor was installed (RPM increase from 1600 to 2350). This met with only marginal success. In fact, it gave the tines more kinetic energy, resulting in greater dusting and a higher probability of knocking fecal particles out the transport tube. This occured only when the slide valve was open for cleaning or inspection purposes. The rate of air flow through the 4-inch diameter transport tube with the "as designed" 30 cubic feet per minute air flow is only 5.7 ft/sec while the circumferential speed of the slinger is 72 ft/sec. Tines striking dried fecal matter imparted enough kinetic energy to drive it out even under 1 G conditions. Another factor was that the upper tines shredded the tissue and carried it along with a fan effect, which probably amplified fecal dust ejection.

Postflight analysis of the material in the commode after the STS-7 flight showed the commode to be about 2/3 full with about 90% of the material being paper. The motor was overloaded due to the tines trying to stir this material. The swept back lower tines tended to sweep the paper down over the lower two-thirds of the hydrophobic filter, tending to reduce its effectiveness and the amount of air flowing through it. This decreased air flow resulted in less ballast air when the commode and urinal were in use together with the consequent probability of overloading the separator and getting liquid in the odor/bacteria filter. Air flow was further decreased due to the high RPM motor creating fecal dust, which clogged the slinger filter.

To cure the problem of waste ejection, both sets of tines were removed by STS-11. This appears to have solved the problem of waste ejection, as no reports of this were made by the flight crews of STS-11 or STS-13. However, it did seem to introduce a new problem of fecal material sticking to the slinger. In one case, the slinger failed as a result of fecal material freezing between the transport tube and the slinger.

2.1.2 Low Air Flow

Ballast air flow for entrainment of both feces and urine not been constant and, in some cases, has been inadequate to draw the feces and urine into the WCS. The current system uses one fan separator to draw the air into the system. This provides 30 CFM for the commode line and 8 CFM for the urine line.

In the urine line, the 8 CFM air flow is rapidly degraded when the fine mesh pre-filter clogs with genital hair and other debris with daily use. The problem is the small surface area of the pre-filter. Currently, this filter must be changed frequently to maintain a satisfactory volume and velocity of air in this line.

2.1.3 Excessive Operating Noise

Several crew members have stated that they have refrained from using the WCS as much as possible during sleep periods due to the noise of operations disturbing those sleeping. Primary sources of noise have been the slinger and the fan separators. The slinger noise should be greatly reduced by the removal of the tines, eliminating the propeller-type noise they generated.

After STS-8, attentuation material was installed on the WCS cover and the sleep compartments were acoustically treated. The crew of STS-9 noted that the WCS no longer disturbed sleep and subsequent crews have had no complaints regarding noise. Still, it is a potential problem which should be evaluated for the possible configuration changes or new WCS concepts.

2.1.4 Limited Commode Storage Capacity

There have been several instances, but most notably from the STS-7 flight, where it became obvious that the WCS would have trouble meeting the specified man-day capacity requirements. For example, post-flight analysis showed that the commode was approximately 2/3 full after 30 man-days of operation, the slinger failed after five days, and there were dust particles ejected from the commode. The crew on this flight used toilet tissue at 2.5 to 3 times the normally expected rate. Perhaps almost all of these problems were directly or indirectly related to commode overloading.

2.1.5 Residual Urine, Particularly With Females

One reason for the greatly increased paper usage on STS-7 may have been the inability of the female astronaut to get rid of the last few drops following urination without the use of paper. This may have been equivalent to adding 4 or 5 more crew members, assuming there were this many urinations in a 24-hour period. The male crew's last drop collection device (offset urinal cap and pinch valve) appears to be satisfactory.

2.1.6 Single Point Failure Modes

A review of the GE WCS Failure Modes and Effects Analysis (RA05A) (Revision C) was conducted under the guidelines that the items were analyzed to determine if all failure modes were covered and if the corrective actions were appropriate for the

failure modes. This review disclosed several failures modes in the water separation system which could cause secondary failure of the odor/bacteria filter. The initial failure of the odor/bacteria filter cannot be detected until water saturates it. Some failures in the mechanical linkage systems may not have been corrected in the manner suggested by the GE FMEA. Several single point failures which can lead to water saturation of the odor/bacteria filter :

1. Obstruction of the particulate fil

2. Obstruction of the orifice

3. Obstruction of the bacteria/debris filter in commode

4. Obstruction of the pitot tube in the fan separtor

5. Obstruction of the dual check valve

6. Failure of the separator/motor shaft coupling

Most of these single point failures are undetectable except the third one until saturation of the odor/bacteria filter occurs and low air flow is noted by the crew. Once the filter is saturated, there still exists the problem of determining which of the above failures caused moisture to enter the odor/bacteria filter. The first failure is easily verifiable by observation of the air inlet screen and the third failure is verifiable through low air flow through the commode. The probabilities of occurence of the second and sixth failures listed are considered to be low and may initially be discarded as the cause of moisture in the odor/bacteria filter. This leaves the fourth and fifth failures which can be isolated by selection of separator No. 1 or No. 2. In any event, the odor/bacteria filter must be changed and diagnosis of the problem verified, otherwise the new filter could also become saturated with moisture and restrict air flow through the WCS.

It is plausible that the early low air flow on STS-7 could have been due to a wet odor/bacteria filter which later dried out. This could have been caused early in the mission by paper wrapping around the slinger filter at a time when the commode and urinal were in simultaneous use, which resulted in reduced ballast air and separator overflow.

Several single point failures can result in the inability to operate the commode operating handle in the open or closed positions. These failures are:

- Binding of the linkage of the commode operating handle
- Binding of the slide valve
- Binding of the vacuum isolation valve
- Binding of the ball valve

If the failure occurs with the handle in the closed position, then the commode is not usable unless the item causing the mechanism is isolated and disconnected from the linkage. In this failure mode, the urine and waste water collection capability is not affected and the use of the contingency collection bag may be required to permit continuing the mission. The ability of the crew to correct the failed component by disconnection of the mechanical linkage through access by the front close out panel must be verified, since access from the sides and back are prohibited when the WCS is installed in the vehicle. Correction of the binding slide valve is feasible, since it is accessible and designed for disassembly and cleaning in flight. An O-ring seal for this valve could be included as a spare for in flight servicing since failure of this seal can result in excessive loss of cabin air. However, replacement of the seal in space may be too complicated anyway, necessitating termination of a mission in any event, so the best answer is to ensure that the seal works. Failure of the mechanism in the open position would result in the inability to close the slide valve and expose the commode to vacuum. In this event, the most accessible linkage to disconnect would be the slide valve, which would allow isolation of the commode from the cabin. The slinger motor would then have to be deactivated through the opening of the appropriate circuit breaker. This would allow contingency operation of the WCS through manual operation of the slide valve and circuit breaker.

2.2 ELECTRICAL DEFICIENCIES

Since the electrical system for the WCS was designed to operate in conjunction with mechanical operation of valves and levers, the requirement for limit switches was deemed necessary. It takes one limit switch to operate the slinger motor and two in series to operate the fan separator motors.

An in-depth review of problems and circuitry of the WCS revealed the following problems associated with its electrical operation:

- Slinger motor failure to operate due to limit switch malfunction

- Fan separator problems associated with limit switches

- Single point failure mode - slinger motor power from one bus

Alternatives exist to increase the reliability and eliminate the single point failure modes of the WCS electrical system. Some of the design options are presented in Section 3.2.

2.3 OPERATIONAL AND TRAINING DEFICIENCIES

In general, there are few operational and training deficiencies. Most operational deficiencies are strongly related to other systems deficiencies. For example, on STS-7, the use of excessive tissue was related to both the storage capacity of the commode tank and the excessive use of tissue. The excessive tissue usage is an operational deficiency. In addition, a training deficiency of note is the lack of emphasis in the manual on limiting use of toilet tissue to minimize the potential for a clogging problem. It is noted in the manual that only tissue is to be discarded in the commode, but a warning should emphasize economy of use.

The WCS system is operationally simple to use and requires relatively little training. The current design of the WCS is unforgiving, however, and an effort has been made in this study to suggest design modifications, alternate design concepts, and operational changes which result in a more forgiving WCS.

3. DESIGN CHANGES

This section concentrates on identifying possible design changes to the existing WCS which may minimize or eliminate problems encountered during operations of the Space Shuttle Orbiter. The primary concerns related to the WCS have been:

- o Collection and retention of wastes
- o Ease of crew usage
- o Noise level of system operation
- o Reliability of system
- o Waste storage capacity
- o Reduction in turnaround time

The first four items in the list have been addressed in the reconfigured system for flight 41-D, the filter bag concept. The elimination of the slinger motor should stop the ejection of fecal waste and dust from the commode. It should improve the overall reliability of the system, since the slinger contributed to problems on seven of the previous Shuttle flights. By elimination of the slinger, the noise level and power consumption should be reduced.

The main item of concern for a filter bag concept is the adequacy of air transport alone to distribute the waste inside the commode. If the results of the configuration for flight 41-D indicate that air transport is insufficient to prevent localized blockage of fecal waste inside the commode, it may be desirable to return to the base line configuration with the slinger motor to aid in mechanical distribution of wastes inside the commode until other options can be flight tested.

In either configuration, the waste storage capacity has not been attained. From previous flights, STS-7 in particular, it has been shown that the bulk of the volume of waste inside the commode has been paper. Even with conservation of paper in subsequent flights, it is estimated that the maximum storage capacity will be around 100 man-days. The past performance of the WCS indicates that three major choices are available to resolve the issue of storage capacity:

- o Design the WCS to be inflight servicable to increase the mission duration capability
- o Reduce the amount of paper disposed in the commode by providing a serarate storage capability for the

clean-up tissues and wet wipes

- O Develop a wipe that (largely) vaporizes or sublimates in a vacuum or with exposure to a gas or ultra violet radiation

Perhaps an in-flight serviciing capability could reduce the on-ground turnaround time required for the Orbiter WCS. Not only could the WCS be serviced during the flights, but access could be made easier for the service required on the ground.

3.1 DESIGN OPTIONS

The choice of design options should wait until the results of the WCS configuration for flight 41-D are reviewed and evaluated. If the filter bag concept shows that adequate collection and distribution of fecal wastes can be accomplished by air transport alone, then the obvious choice will be to proceed with an in-flight serviceable WCS using a filter bag concept. If the evaluation of the WCS configuration for flight 41-D mission indicates that there is too much localized lumping of fecal wastes directly in line with the transport tube, leading to premature limitation of storage capacity inside the commode, it may be desired to retain mechanical distribution of fecal material as afforded by the base line slinger configuration of the WCS and to approach the storage capacity problem by providing an alternate storage capability for cleanup tissues and wet wipes.

3.1.1 Flight Servicable WCS

If the evaluation of the WCS configuration for flight 41-D indicates that comparable performance in waste collection can be obtained by using a filter bag inside the commode, then the preferred choice of design improvement would seem to be to add in-flight servicability features to the WCS. With in-flight serviceability, the WCS man-day capability is constrained only by the available storage volume allocated for the used full filter bags. It is anticipated that for high man-day missions, additional storage volume would be available in the attached Space Lab or other habitable module located in the payload bay. In-flight serviceability could be achieved by the following steps:

- O The upper cover of the WCS would have to be modified to be easily removable by the flight crew. Specific changes to the WCS cover would be installation of quick release fasteners such as Dzus fasteners instead of the conventional screw fasteners. Also, access to all of the fasteners must be available while the WCS is installed in the Orbiter as shown in Figure 1. The panel areas beneath the controls should be made

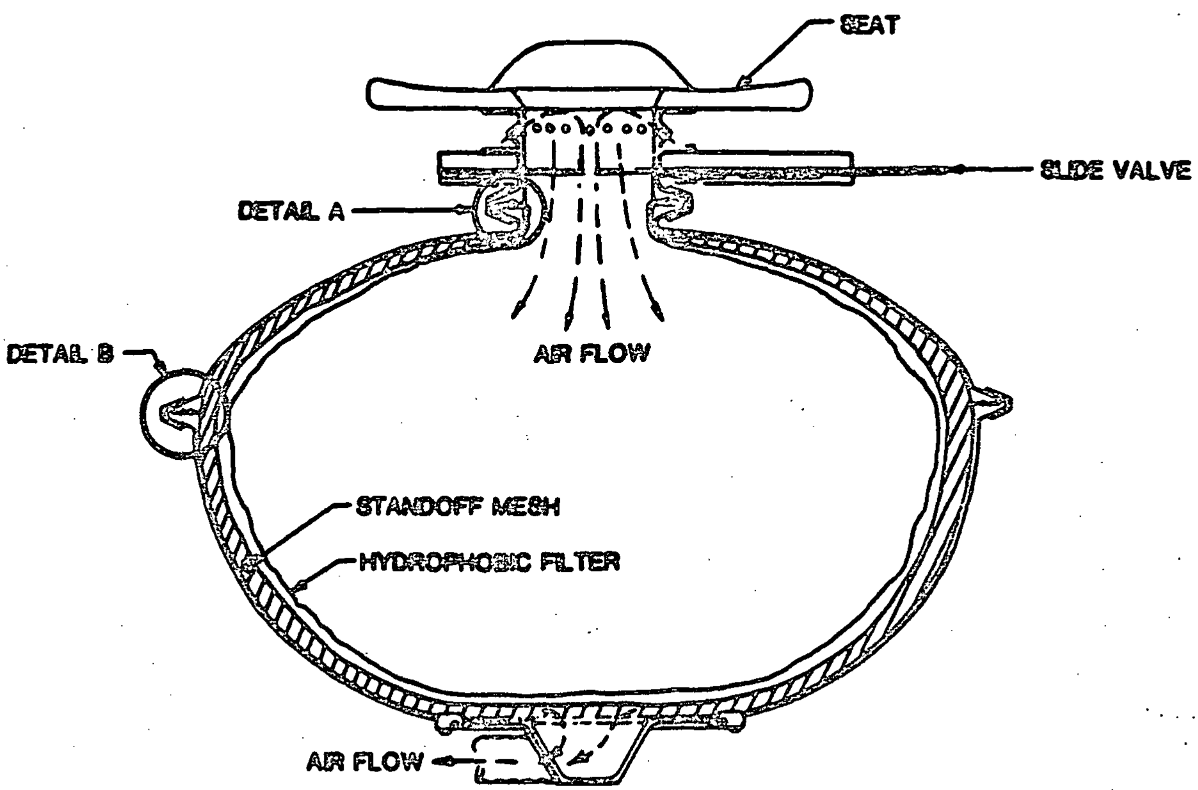


Figure 1

IN-FLIGHT SERVICEABLE WCS CONCEPT WITH LINER

separate from the top cover to allow removal of the cover without disturbing the control panels and mechanisms.

- The slide valve must be easily disconnected from the rest of the WCS linkage. A quick disconnect which can be manually operated, such as by using pip pins, is preferred to the existing bolted linkages and pins with E-clips at the rotating clevis couplings.

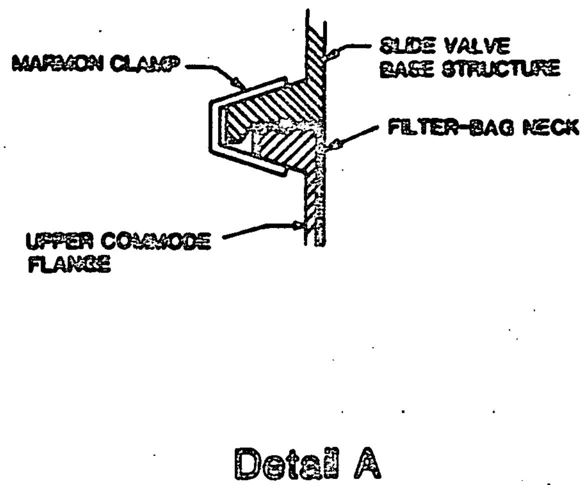
- A clamp or rotating ring retainer should be located between the slide valve and the commode container. This clamp should also secure the upper neck of the filter bag to the container as shown in Figure 1.

- A mating flange near the midsection of the WCS container should be installed to allow easy removal and installation of filter bags inside the container. Details of the flange, such as the one shown in Figure 2, should be considered in the design. These include the retention of two O-rings, beveled recess in the flange mating halves for centering alignment, and the use of some type of closure to provide mechanical preload on the mating flanges. When the commode is exposed to vacuum during the drying cycle, cabin pressure will assist in maintaining pressure on the mating halves of the flanges.

3.1.2 Separate Waste Paper Storage

It may be necessary to provide separate waste paper storage if vaporizing wipes are not developed, in-flight servicing of the base line WCS is not considered practical, or disposal of waste paper and wet wipes in the commode limits the capacity of the WCS to approximately 100 man-days. From previous flights, it has been determined that the paper in the commode constituted from 70% to 90% of the volume of the material inside the commode.

If most of the used toilet tissue and wet wipes were temporarily stored in a container adjacent to the commode, the existing WCS design could be retained to accommodate the long duration, large crew missions. This could be accomplished by disposal of the first tissue following toilet use into the commode, and disposal of subsequent tissues and wet wipes for hygenic clean-up in a separate waste container located on the left hand wall in the WCS area. The temporary storage container should house a disposable liner and be vented through the quick disconnect leading to the wet trash vent line. As the waste paper fills the container, the liner could be periodically removed and stored in the wet trash storage area located across the cabin.



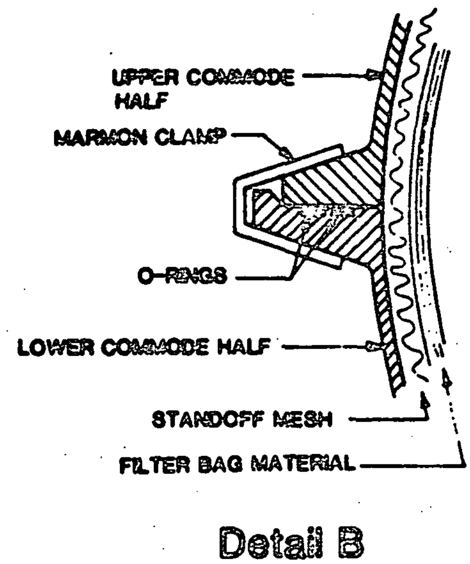


Figure 2

CONNECTION/CLAMP EXAMPLES FOR IN-FLIGHT SERVICEABLE WCS

The recommended location of waste paper storage container is shown in Figure 3. The size of the container should be maximized without interfacing with crew usage of the WCS. By maximizing the size of the container, the frequency of replacement of the disposable liners is reduced to a minimum.

The waste paper storage container should house a disposable bag with a hydrophobic bacteriological filter located in the base of the filter with a fold over lip at the opening. The fold over lip should help secure the bag in the container while in use and velcro hook and pile on two faces of the lip would allow for closure of the bag when it is removed for replacement and stowage in the wet trash volume. A spring loaded lid, with an opening detent, should seal the waste paper storage volume when it is not in use. Manual placement of waste paper in the bag should automatically ensure some tissue compaction and simplify the disposal of the waste paper. Anti-bacterial agents in the wet wipes should also minimize odors and retard bacteria growth.

A prototype to evaluate the feasibility of separate waste paper stowage could be fabricated from fabric and attached to the wall of the WCS area by velcro to determine the optimum location for use in a zero-G environment. This unit should also be vented to the quick disconnect leading to the wet trash vent line.

3.1.3 Fan/Water Separator

Another element in the WCS which has created problems in the past is the fan separator. In more than one instance, the fan separator has become flooded and caused difficulty in operation of the WCS.

A critical element in the fan separator is the pitot tube in the fan separator shown in Figure 4. This tube has an opening of only .090 inches diameter and relies on the tangential flow velocity of the liquid inside the rotating fluid reservoir to provide the pressure head to overcome the check valves and to transport the waste water and urine to the storage tanks. The small inlet diameter renders the pitot tube extremely susceptible to failure either from solids build-up or from foreign material obstruction. This small diameter is also the factor which limits the maximum fluid flow capacity of the fan separator assembly. If the pitot tube inlet diameter is increased to be slightly smaller than the smallest cross section area in the remainder of the fluid collection system, it would increase the flow volume out of the fan separator without affecting the pressure head, since pressure is a function of the tangential velocity of the rotating fluid reservoir and not a function of the pitot tube inlet area.

Orbiter Mid Deck

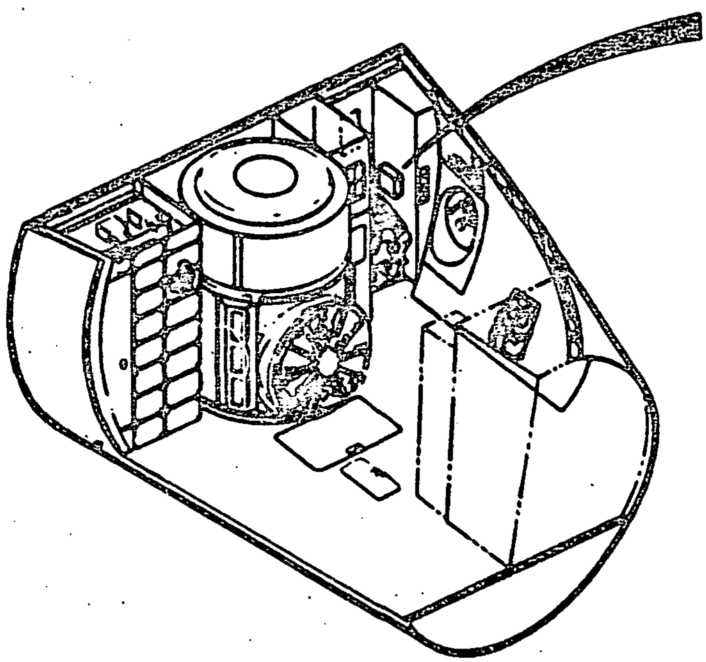


Figure 3

TEMPORARY STORAGE OF USED TISSUE AND WIPES

Fan Seperator Assembly

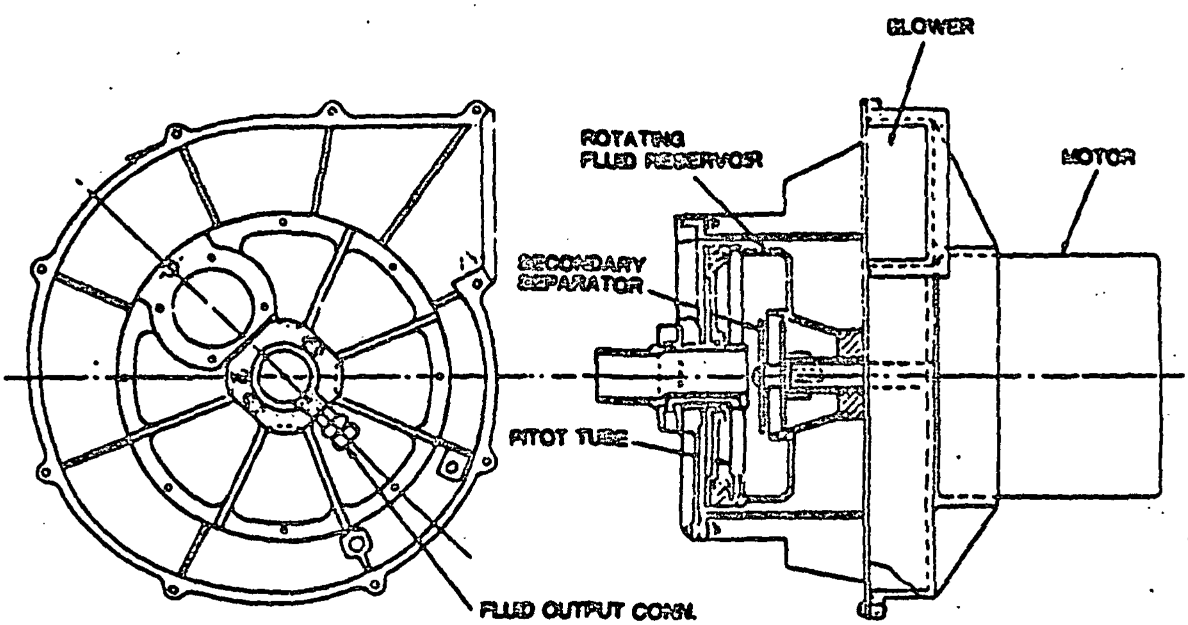


Figure 4

PITOT TUBE IN THE FAN SEPARATOR ASSEMBLY

This change would also reduce the probability of blockage of the pitot tube inlet.

If the water separator is redesigned as outlined above, consideration should be given to the addition of second pitot tube in each separator. This would ensure internal redundancy against flow blockage, increase the fluid flow capacity, and reduce the time required to clear fluid from the fan separator.

Several flight occasions of the slinger stalling or slowing have been reported and all have been due to some type of obstruction inside the commode.

The original purpose of the slinger was to break up the fecal matter and deposit it on the outer commode walls through centrifugal force. It now appears that breakup of the fecal matter may neither be required nor desirable and that deposition of the outer walls is either not occuring or is not effective. The slinger does not perform its intended task well and causes some of the most recurrent and annoying WCS problems during the process. For these reasons, it is suggested that any redesigns should avoid use of the slinger and slinger motor.

The other problems with the commode are associated with airflow blockage or with capacity. The blockage again can be traced to the slinger filter.

The remaining unresolved problems of the urinal are associated with either last drop collection from female users, or urinal line airflow degradation.

An analysis and proposed solution to the female use problem was presented in the earlier EEI report. The solution presented was straightforward, uncomplicated, and inexpensive to implement. The recommendation to incorporate the EEI proposed change (collection wand) remains.

Urinal line airflow volume degradation is seemingly caused either by fan/separator malfunction or by clogging of either the urinal prefilter and screen or the odor/bacteria filter. Fan separator malfunctions appear to be electrical in nature whereas the clogging problems are apparently due to lack of proper cues for performance of in-flight servicing on the filters.

3.2 RECOMMENDATIONS

The following design changes are departures from the WCS basic system as modified for flight STS 41-D (13). They are

not intended in any way as a comment on or endorsement of the flight 41-F configuration.

3.2.1 Mechanical Design Change Alternatives

Options conceived for modifying the existing mechanical design of the WCS include:

- O Incorporate the urinal prefilter and screen into a single flight serviceable or replaceable unit. Increase the filter and screen capture area to accommodate the maximum crew on-orbit time. Placement of the filter/screen further downstream for possible integration into the WCS main structure will provide the greatest design latitude in terms of size and will unencumber the urinal hose of the prefilter/screen assembly. The filter could be a cone-shaped filter similar to that used in washing machine inlet water lines and in garden hoses. Using the same mesh size, this time proven filter design will increase the surface area while permitting debris to build at the end of the cone, leaving the sides free for liquid and air passage. For efficient functioning of such a filter, the cross-section of typical debris collected by it must be small relative to the radius of the filter.

- O Consider operating both fan separators simultaneously. Simplify the plumbing by removal of the 5.28 A and B valves and replacement with tee connections. By running both separators in parallel, this flow could be increased to 45 CFM in the commode branch and 15 CFM in the urine branch. That change recommendation is predicated upon a system analysis to verify that the fan separators operate properly under those conditions and that problems are not introduced in the event of a failure of one fan separator. Add check valves as required to prevent flow short circuit if one fan fails. This change will increase the suction pressure and air flow rate in the urinal which will improve both performance and user acceptance. Incorporate electric switching changes associated with this change.

- O Add a venturi-type delta pressure transducer upstream of the odor/bacteria filter as recommended by the earlier EEI report. With a visual or audible cue, the crewman will be alerted when flow is degrading and servicing is required.

The following commode redesigns should be incorporated as a group. Implementation of one redesign without the others

may not necessarily result in an improved system. Some of these redesigns have been previously recommended. Crew comments indicate that operation of the commode in an "outhouse" mode is satisfactory. All of these changes are meant to develop a mode of operation as the optimal concept in terms of simplicity, low noise generation, low crew training and service time, and minimal power requirements.

- Remove slinger, slinger motor, debris filter assembly, and all associated electrical plumbing. Leave the commode airflow exit manifold as currently located on the commode tank and similar to the flight STS 41-D configuration.

- Remove the transport tube and design a flight changeable bag which will conform to the interior shape of the commode. This bag to be backed by a mesh material which will permit airflow drawn in through the underseat air inlet to flow through the bag wall and then be drawn to the collection manifold and into the fan separator assembly. The bag should have a hydrophobic inner liner which will prevent liquid from forming ice in the vent lines during vacuum drying. The bag should include a closure device such as a flap and drawstring for sealing prior to removal from the commode.

Although the fecal matter will not be broken up, and thus will not pack in, the natural airflow pattern inside the commode will tend to transport all solids (and liquids) away from the seat and outward leaving the middle or center volume open. As the bag begins to fill, the materials then deposited will drift toward the least obstructed area of the wall and should, by this method, tend to fill the bag uniformly. The WCS configuration for STS 41-D may either prove or disprove this design concept with sufficient use. The delta pressure sensor and/or inspection will indicate when the bag begins to fill and changeout is needed.

- Redesign the commode bowl to provide a parting flange of some type located in the upper hemisphere. The placement of this flange is not critical so long as it is located so the bag can be removed through the flange opening. This change will no doubt require further redesign of the commode enclosure to allow access, make structural adjustments, etc.

- Redesign the underseat air inlet channels to direct (at least part of) the air slightly away from the buttocks (as recommended in the earlier EEI report). This change will induce a slight downward force to assist

in stool separation and deposition on the commode walls. It is intended to abate the uncomfortable sensation of a high velocity stream of air upon the buttocks of the user. It will be particularly important to incorporate this change if both fan separators operate simultaneously. Then it is estimated that air velocity would increase enough to cause rippling of the buttocks which is probably unacceptable from the user standpoint.

Airflow patterns within the commode should be evaluated by testing a transparent model of the commode with smoke injected through various underseat air inlet duct configurations. Figure 5 shows the various design changes.

- O Incorporate an improved fan/water separator into final design configuration.

Other mechanical schemes for commode design have been examined. The schematics presented in the GE technical proposal cov3rs the gamut of possiblities fairly well. Compared to the removable bag proposal, all of those concepts are more complex which will undoubtedly result in more problems and cost. In addition, most would require additional Shuttle volume, additional power, and more complex training and operational procedures. There is little, if any, incentive to propose any of those schemes as viable options until the removable bag concept is thoroughly evaluated in flight.

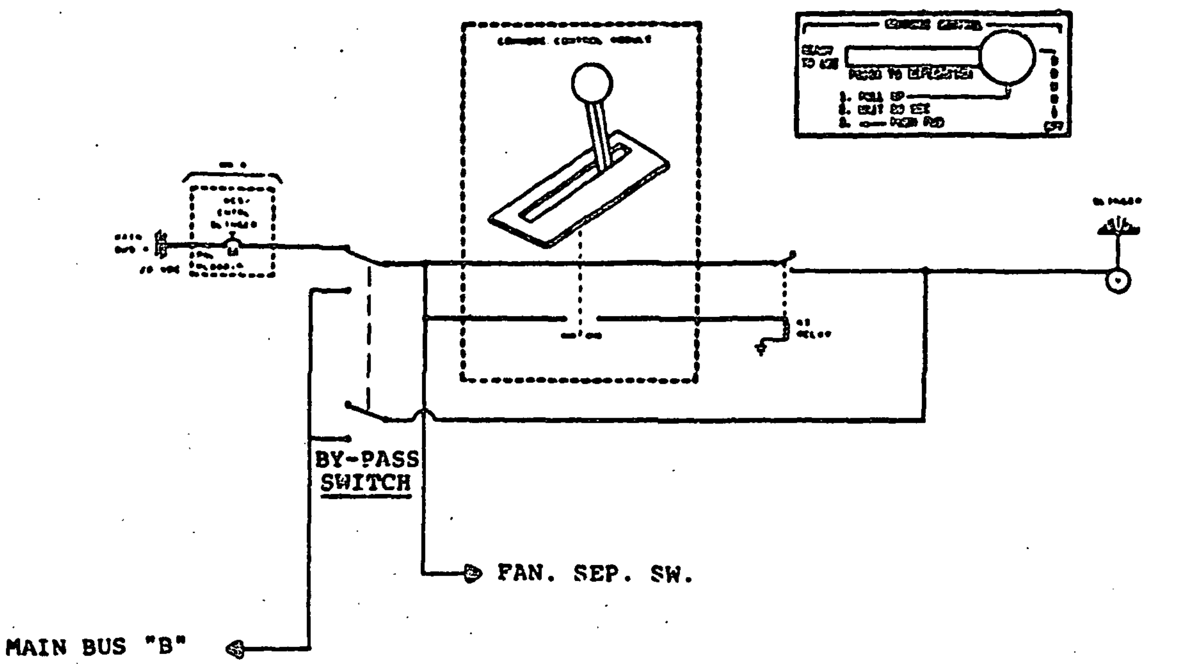
3.2.2 Electrical Design Change Alternatives

If the slinger remains a part of the design, it is recommended to remove the relay K_3 and place the limit switch directly in line where the K_3 relay contact is now. This eliminates a component which represents a single point failure. To prevent the limit switch from being a single point failure prospect, a bypass toggle switch should be installed in parallel with it. Use of a two-pole double-throw switch (shown in Figure 5) will eliminate the single point failure mode of bus power to the slinger identified earlier.

A recommendation is made to increase the airflow in the commode by running both separator fans simultaneously. To do this, it is proposed that the urine diverter valve (5.28 A) and the ball valve (5.28 B) be modified. The need for these valves is questioned. If this plumbing could be straight teed, the electrical operation of the fan separators could be simplified by eliminating all limit switches. It would allow a simple

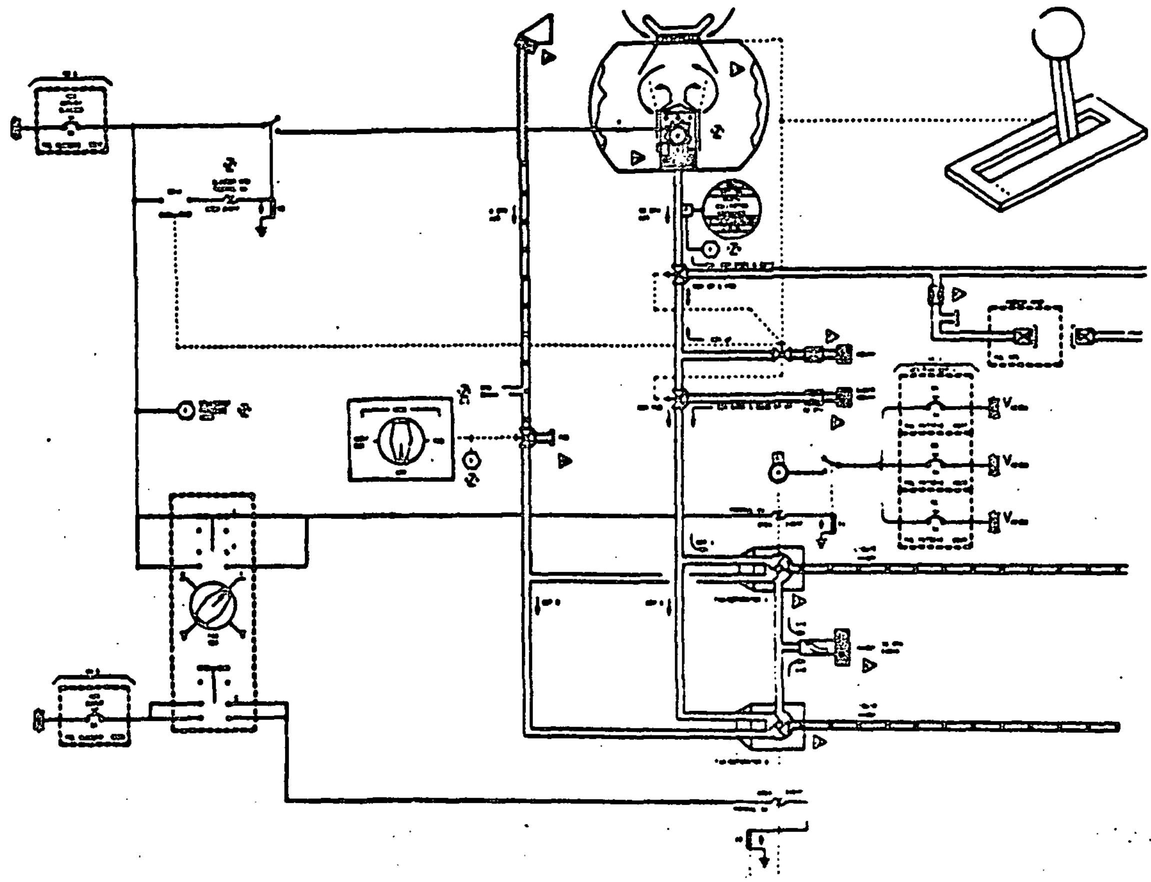
method of operating both fan separators simultaneously which might also remove the restriction against urination while dumping the EMU.

Removing the valves would eliminate the need for the mechanical operation of the fan separator switch. It could be replaced with a purely electrical switch (see Figure 6). The mode select switch could be modified by removing the electrical operation and letting it be a purely mechanical switch to operate the WCS/PHS valve. The mode control switch and the fan separator switch should have their location switched to ease the operation of the WCS by the occupant if these changes were made.



WCS SLINGER ELECTRICAL CIRCUIT ALTERNATIVE

Figure 5.



FAN SEPARATOR SWITCH ALTERNATIVE WITH PLUMBING CHANGES

Figure 6.

4. NEW DESIGN CONCEPTS

New design concepts were desired with a view to identifying alternatives to the existing Orbiter WCS which can replace the existing system and to identify new concepts for Space Station application. The assumed ground rules are:

- O WCS must fit within the existing volume constraints specified for the Orbiter
- O System design requirements specified in Section 1.0 of this report apply
- O Evaluation primarily compares solid waste collection and assumes that liquid waste collection is the same for each system.

If application to the Space Station is considered, any WCS concept is assumed to be serviced after 210 man-days of usage. Servicing of WCS must be accomplished on the Space Station.

Waste Collection Systems in general have three basic subsystems:

- O Collection - waste gathering for subsequent removal
- O Transfer - transporting the waste between the collection subsystem and the disposal facility
- O Disposal - disposing of the waste

A WCS design must address each of these subsystems. For example, a residential WCS uses a water closet and pressurized water and gravity for the collection subsystem. Transfer and disposal are both accomplished by pipes partly filled with entraining water which is driven by gravity. Of course if a septic tank is used, a storage tank is also included in the disposal system. By comparison, the current zero-G WCS uses the seat, fan separator air flow combination for collection, the slinger for transfer and the tank for disposal/storage.

4.1 DESIGN OPTIONS

New configurations to be evaluated include:

- O Commode with removable filter bag
- O Base line WCS with separate waste paper storage container

- Commode with mechanical compactor

- Bidet type of commode

- Squirrel cage blower commode

The first two configurations have been discussed in depth in Section 3 of this report and should serve as basis of comparison for alternate design concepts.

A simple concept for a mechanical compactation design may include a flexible bladder inside the commode container. This configuration would require a filter bag type liner since any item such as the base line slinger motor would interfere with the compactation process. Assuming that a compactation ratio of three times that presently found with the base line WCS can be achieved, the system should be able to support the maximum duration Shuttle mission. One concern is whether the compaction of the wastes would interfere with the airflow through the commode. A possible solution would be to place the air outlet near the top of the commode which would be covered before the compacting cycle began, thus preventing blockage of the exit airflow. Turnaround would require removal of the entire WCS as is presently done, or at least replacement of the commode container. Application to Space Station would be straight forward but would require a regular exchange of commode containers from Earth.

A WCS using the bidet concept of water rinse instead of the use of tissues has a certain appeal in minimization of solid wastes. Such a system would require a means of solid waste and rinse water separation from the transport air flow. Additionally, the solids would have to be retained while the water is evaporated or separated to prevent excessive storage volume. A means for achieving this could be to use a rotating container where the solids separate to the outermost perimeter with liquids closer to the center of rotation and the air flow in the space closest to the center of rotation.

Drying of the crew member after the water rinse could be accomplished with warm air to eliminate the use of toilet tissues. Whether this could be achieved with reasonable crew comfort is subject to discussion and substantial prototype development.

A major drawback of a water rinse system would be the necessity to use significant quantities of water and to evaporate it after use. The evaporation of the amount of water anticipated to be necessary to achieve satisfactory rinse cleaning of the crew member after defecation may cause excessive water vapor in the

area of the Orbiter (or Space Station) and have adverse effects on its payloads and onboard experiments. For this reason, it is considered undesirable to pursue the use of water rinse as an option in the WCS design evaluation.

A variation on the filter bag concept may provide good Space Station compatibility. This concept uses a hydrophobic bag filter and a squirrel cage type blower. The blower is contained within a tank similar to the current one. It provides the required air flow for separation plus significant additional flow for entrainment. The collection subsystem is similar to the current zero-G collection system except that the air flow is provided by an integral blower instead of a peripheral item, and the flow rate is significantly increased. Transfer to the bag filter is accomplished by entrainment in air which is driven by the blower and by kinetic energy imparted to the waste by impingement on the blower blades. Waste disposal occurs in the bag filter which could be replaceable in flight. Since the bag outer liner is hydrophobic, both solid and liquid waste will be retained. Vacuum drying will remove water as it does in the current WCS. Evolution to an operational Space Station WCS should be straight forward and should provide design flexibility. Bag replacement provides high capacity for a distributed WCS concept and modification could permit disposal to a centralized waste processing system.

The Squirrel Cage/Bag Filter concept will involve significant development and qualification costs. Its relative ease of in-flight service may warrant consideration especially when looking for extension to the Space Station.

4.2 RECOMMENDATIONS

The concept of water rinse should be eliminated on the bases of generating excessive water vapor around the Orbiter and requiring significant consumables. The advantage of any means of mechanical compactation of fecal waste may only be to improve the mean time for servicing. It is estimated that mechanical compactation can extend the time before servicing is required by a factor of three to four over the existing base line WCS. This extention of the time between servicing would come at the expense of a major new design start and does not ensure that any of the other design objectives such as reliability, weight, volume, or ease of use will be obtained.

It is recommended that the replaceable filter bag liner and separate storage at waste paper, be seriously considered as the two viable options for the WCS design on the Orbiter.

5. OPERATIONS CHANGES

Although the identified possible changes in operations generally entail design modifications, the modifications necessary to effect these suggestions are not detailed since there is often more than one way to accomplish the desired result.

One of the problems identified in Section 2.1 is that waste has escaped from the WCS into the cabin. Specifically, feces dust has been ejected from the WCS. A variety of options exist which may alleviate this problem including:

- o Eliminate the slinger
- o Retain or restore feces cohesiveness for loose particles
  - Incomplely dry the feces
  - Spray a small amount of water to transport feces dust to the WCS inner wall for adherence when the WCS is repressurized
- o Oxidize the feces allowing the gases to escape into space

A possible way to incompletely dry the feces would be to retain some pressure in the WCS, lowering the pressure just slightly below the vapor pressure of water and allowing some repressurization after a suitable time. Many of the objectionable sulphurous volatiles would probably be driven off during this time minimizing the odor problem. A possibility for further minimizing the odor problem could employ nitrogen for the repressurization to minimize odor generation through oxidation. A significant drawback to any of these ideas is that their implementation will introduce added complexity into the WCS.

6. SYSTEM REQUIREMENTS DEFINTION

The purpose of this system requirements definition section is to expedite the procurement of a flight test article. This flight test article is to be representative for concept verification and subsequent production of the selected improved waste collection subsystem design for use on the Space Shuttle Orbiter.

The systems requirements defintion documentation support will be developed and submitted as a separate report in October.

APPENDIX E

EAGLE ENGINEERING MID-TERM PRESENTATION

This appendix represents the mid-term presentation made by Eagle Engineering, Inc. to the General Electric Company, as part of the requirements of Contract Number TO-84-77, under NASA Contract Number NAS9-17182.

IMPROVED WASTE COLLECTION SUBSYSTEM

DESIGN CONCEPT DEFINITION

MIDTERM PRESENTATION

6 SEPTEMBER 1984

GE SUBCONTRACT TO

EAGLE ENGINEERING, INC.

EAGLE ENGINEERING, INC.

AGENDA

DESIGN CONSIDERATIONS	D.G. HERVEY
DESIGN DEFICIENCIES	D.G. HERVEY
MECHANICAL DESIGN IMPROVEMENT IDEAS	D.G. HERVEY
ELECTRICAL DESIGN IMPROVEMENT IDEAS	R.E. MUNFORD
NEW DESIGN IDEAS.	D.G. HERVEY
QUESTIONS & RESPONSES	R.E. MUNFORD, M.A. CARSON J.K. HIRASAKI, P.G. PHILLIPS

EAGLE ENGINEERING, INC.

DESIGN CONSIDERATIONS

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ENGINEERING, INC.

GE CONTRACT SOW REQUIREMENTS (PARTIAL LIST)

GENERAL

- SEPARATE WASTES FROM CREW MEMBER
- SAFE, ODORLESS STORAGE OF WASTES

SPECIFIC

- ACCOMMODATE BOTH MALE & FEMALE
- CAPACITY NOT LIMITED BY PAPER
- MINIMIZE CREW TRAINING
- NO HANDLING OF WASTES BY CREW
- PROVIDE STOOL SEPARATION DURING USE

EAGLE ENGINEERING, INC.

GE CONTRACT SOW REQUIREMENTS (PARTIAL LIST)

SPECIFIC (CON'T)

- O 210 MAN-DAYS USE CAPACITY
- O BE QUIET DURING OPERATION
- O MAINTAINABLE AT LAUNCH SITE
- O MINIMIZE EXPENDABLES, WEIGHT, POWER & VOLUME
- O BE RELIABLE
- O BE RETROFITABLE INTO CURRENT SHUTTLE COMPARTMENT

EAGLE ENGINEERING, INC.

BASIC SYSTEMS

- O COLLECTION - COLLECTS WASTE FOR LATER REMOVAL
- O TRANSFER - TRANSFERS WASTE TO DISPOSAL FACILITY
- O DISPOSAL - DISPOSES OF THE WASTE

MEDIA

- O WATER
- O AIR
- O CHEMICAL
- O VACUUM

EAGLE ENGINEERING, INC.

OPERATIONS AND REDESIGN OPTIONS

URINAL

- O INCORPORATE PREFILTER & SCREEN INTO SINGLE UNIT
  - INCREASE FILTER AREA
  - FLIGHT SERVICEABLE AS ONE UNIT
  - RELOCATE ONTO STRUCTURE
- O ADD FEMALE URINAL CAP
- O OPERATE BOTH FAN/SEPARATORS SIMULTANEOUSLY
- O ADD VENTURI DELTA PRESSURE TRANSDUCER

REDESIGNS OPTIONS

COMMODE

- O REMOVE SLINGER/MOTOR ASSEMBLY
- O REMOVE TRANSPORT TUBE
- O FLIGHT CHANGEABLE COMMODE LINER BAG
  - HYDROPHOBIC, POROUS
  - AIR RETURN MANIFOLD AT OUTER WALL
  - FLAP & DRAWSTRING FOR SEALING
  - STS 41-F CONFIGURATION
- O PARTING FLANGE ON COMMODE BOWL
- O REDIRECT UNDERSEAT AIR FLOW

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DESIGN DEFICIENCIES

EAGLE ENGINEERING, INC.

WCS OPEN PROBLEMS

PROBLEM	CAUSE
o SLINGER STALLING OR SLOWING	OBSTRUCTION INSIDE COMMODE
o FECAL MATTER EJECTION INTO CABIN	SLINGER
o COMMODE AIR FLOW BLOCKAGE	FILTER STOP-UP
o COMMODE CAPACITY	PHYSICAL PARAMETERS
o URINAL FEMALE LAST DROP COLLECTION	AIR CFM IN COLLECTION CUP TOO LOW
o URINAL FLOODING AND FLOW DEGRADATION	FAN/SEPARATOR MALFUNCTION FILTER BLOCKAGE

EAGLE ENGINEERING, INC.

OTHER CONSIDERATIONS

- OUTHOUSE MODE ACCEPTABLE
- MOST EARTHLIKE OPERATION
- CHEAP, QUIET, SIMPLE, LOW EXPENDABLE USE, LOW WEIGHT
- NEED SMOKE TEST VERIFICATION OF CONCEPT

ENGINEERING, INC.

MECHANICAL DESIGN IMPROVEMENT IDEAS

EAGLE ENGINEERING, INC.

REDESIGNS OPTIONS

COMMODE

- O REMOVE SLINGER/MOTOR ASSEMBLY
- O REMOVE TRANSPORT TUBE
- O FLIGHT CHANGEABLE COMMODE LINER BAG
  - HYDROPHOBIC, POROUS
  - AIR RETURN MANIFOLD AT OUTER WALL
  - FLAP & DRAWSTRING FOR SEALING
  - STS 41-F CONFIGURATION
- O PARTING FLANGE ON COMMODE BOWL
- O REDIRECT UNDERSEAT AIR FLOW

EAGLE ENGINEERING, INC.

OPERATIONS AND REDESIGN OPTIONS

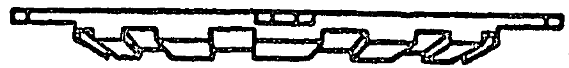
URINAL

- INCORPORATE PREFILTER & SCREEN INTO SINGLE UNIT
  - INCREASE FILTER AREA
  - FLIGHT SERVICEABLE AS ONE UNIT
  - RELOCATE ONTO STRUCTURE
- ADD FEMALE URINAL CAP
- OPERATE BOTH FAN/SEPARATORS SIMULTANEOUSLY
- ADD VENTURI DELTA PRESSURE TRANSDUCER

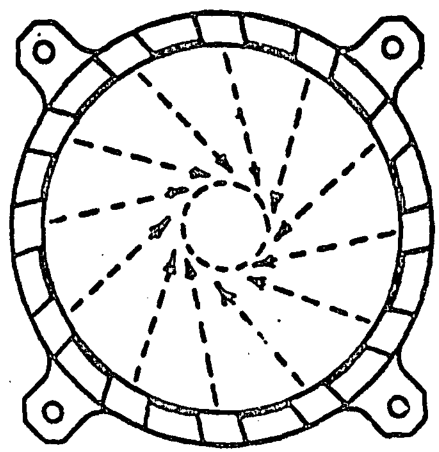
C-4

EAGLE ENGINEERING, INC.

COMMODE UNDERSEAT DIRECTED AIR FLOW



-- SLOTS ANGLED DOWN

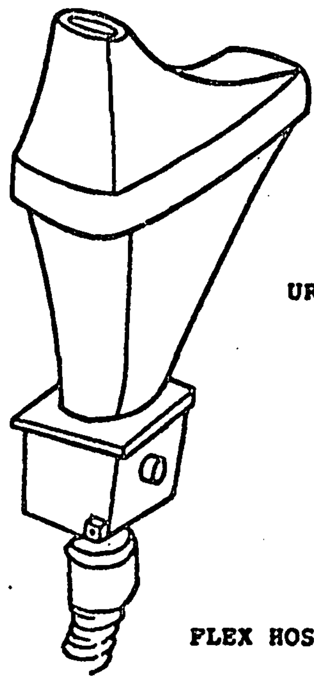


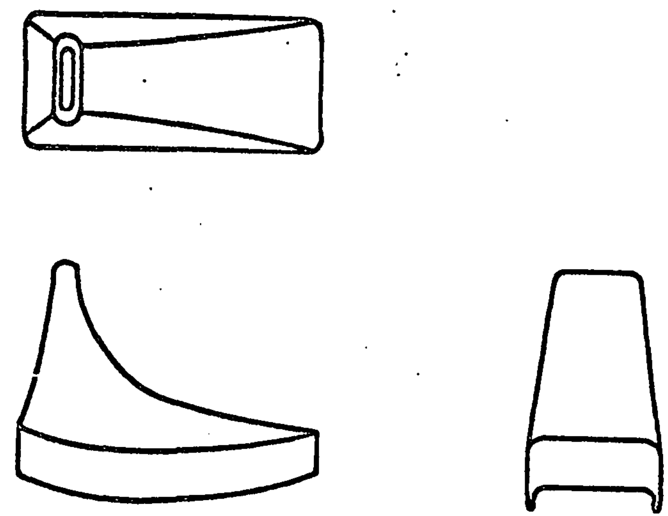
-- SLOTS ANGLED TO DIRECT AIR IN A ROTATING MOTION DOWN TRANSPORT TUBE

EAGLE ENGINEERING, INC.

URINAL CAP FOR FEMALES' LAST DROP COLLECTION

-- VACUUM DRY CAP --





THREE-VIEW

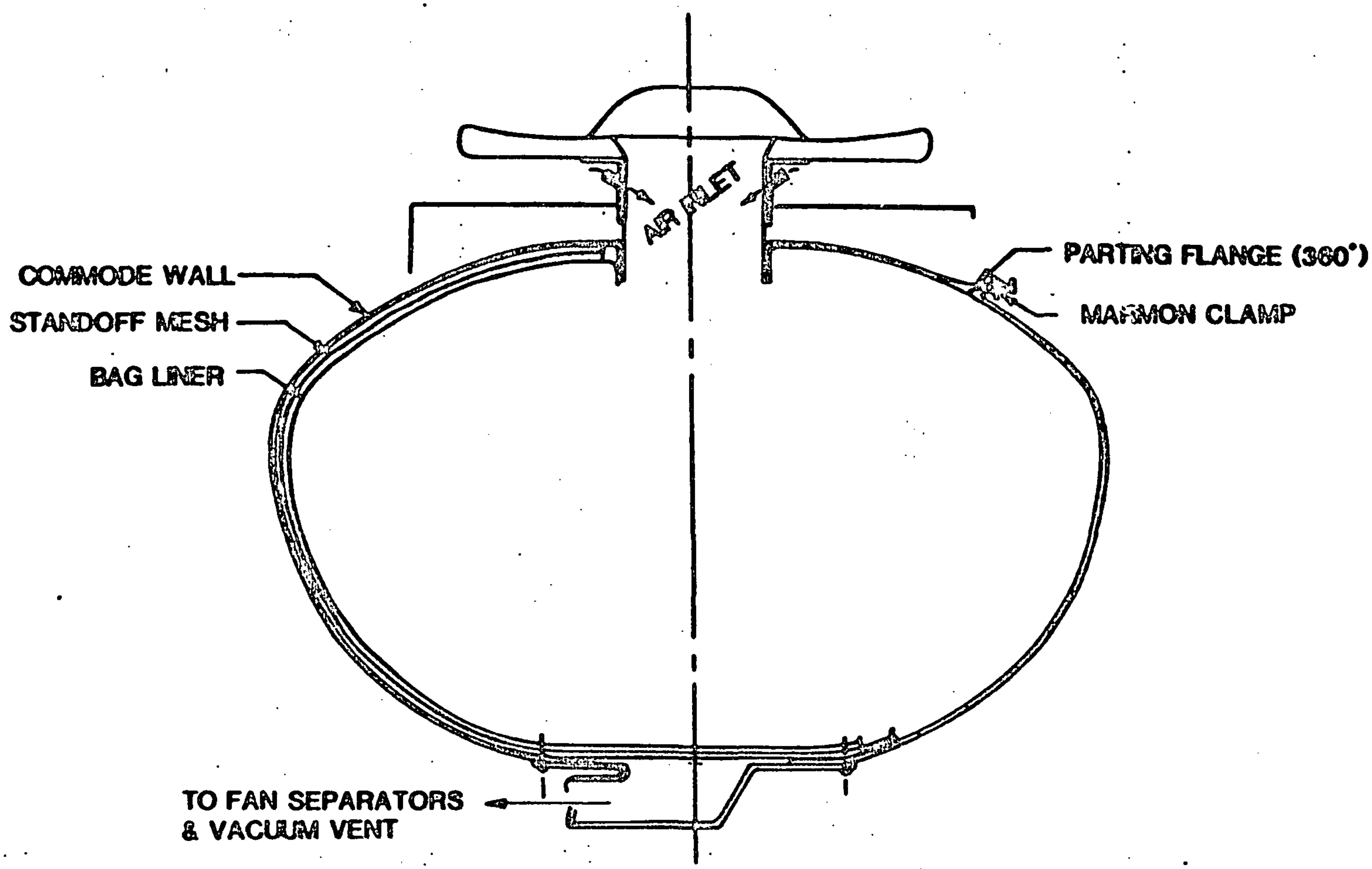
EAGLE ENGINEERING, INC.

WCS ALTERNATE DESIGN CHOICES

- IN FLIGHT SERVICEABILITY TO INCREASE MISSION DURATION CAPABILITY
- REDUCE THE AMOUNT OF PAPER STORED IN COMMODE BY PROVIDING SEPARATE STORAGE FOR CLEAN-UP TISSUES

FLIGHT SERVICEABLE WCS

- O MODIFY COVER TO BE EASLILY REMOVED IN FLIGHT
- O DESIGN SLIDE VALVE LINKAGE FOR QUICK DISCONNECT
- O CLAMP BETWEEN SLIDE VALVE & CONTAINER
- O CLAMP AT MID-SECTION OF CONTAINER
- O STORE FULL BAGS IN TRASH STORAGE VOLUME


AIR INLET
PARTING FLANGE (360°)
MARMON CLAMP
COMMODE WALL
STANDOFF MESH
BAG LINER
TO FAN SEPARATORS
& VACUUM VENT

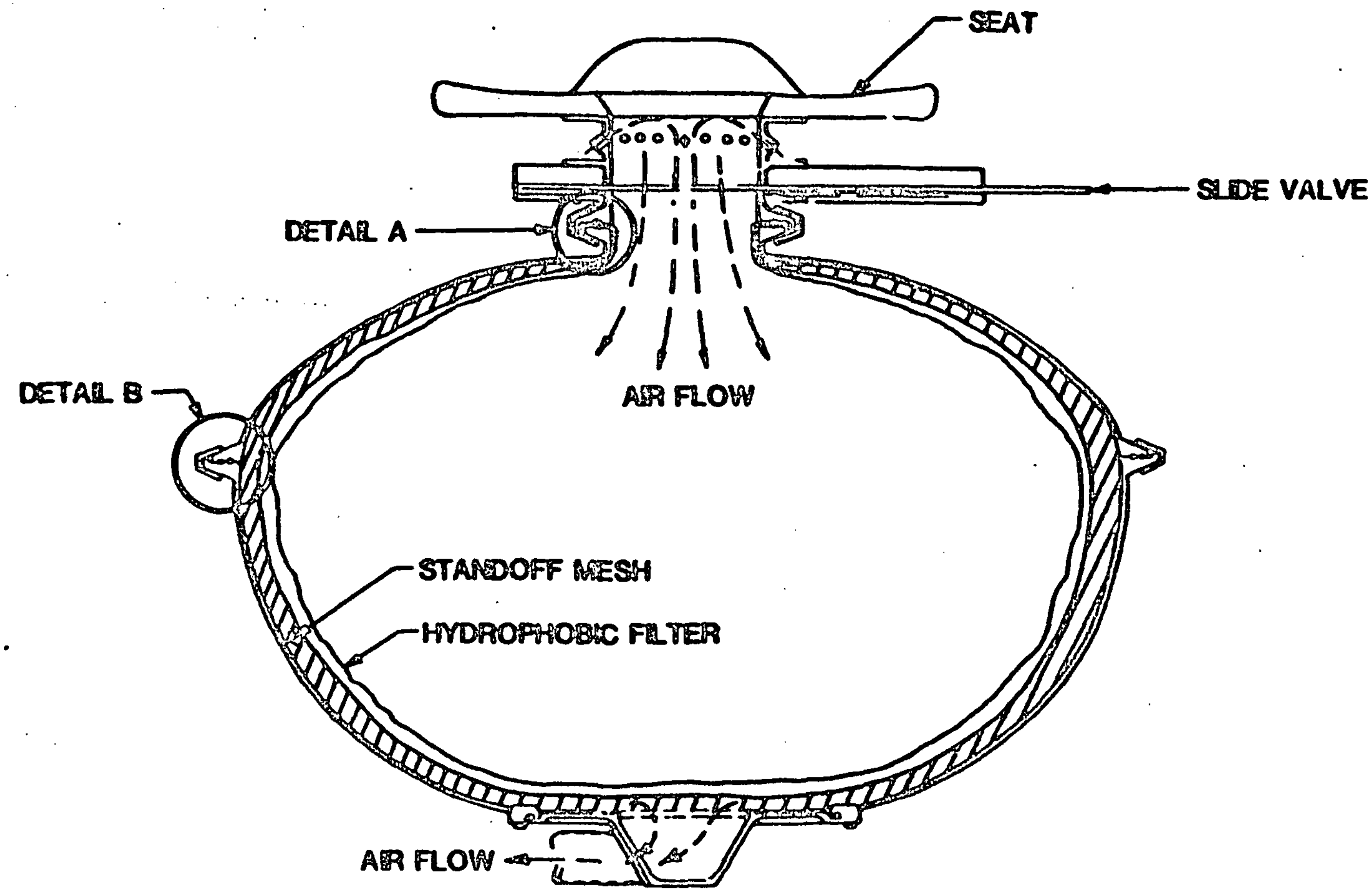
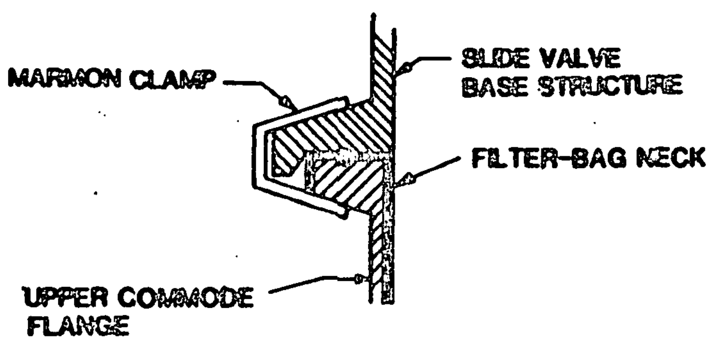
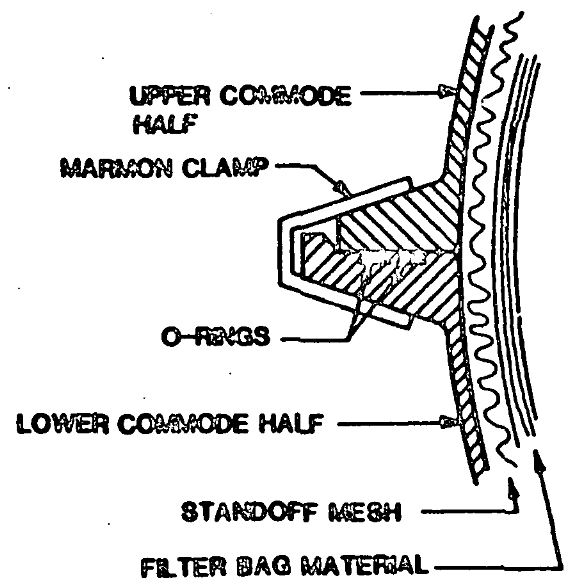

SEAT
SLIDE VALVE
DETAIL A
DETAIL B
AIR FLOW
STANDOFF MESH
HYDROPHOBIC FILTER
AIR FLOW

FIGURE 1



Detail A



Detail B

ENGINEERING

Orbiter Mid Deck

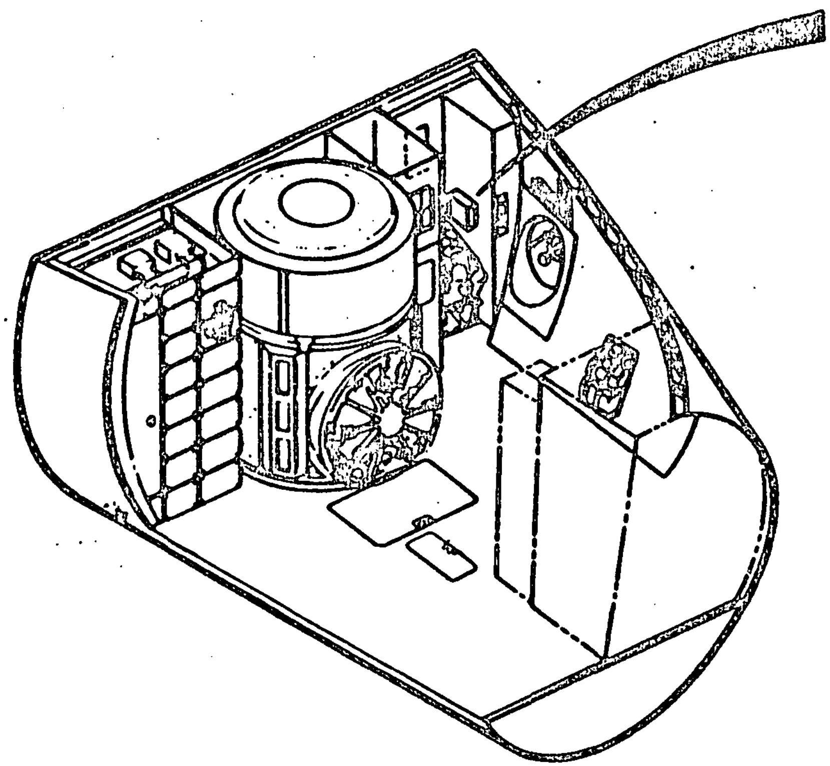


FIGURE 3

EAGLE ENGINEERING, INC.

SEPARATE WASTE PAPER STORAGE

- ABOUT 80% OF VOLUME IN COMMODE IS WASTE PAPER
- SEPARATE STORAGE OF CLEAN-UP TISSUES
- LOCATE TEMPORARY STORAGE CONTAINER IN WCS AREA
- PROVIDE REMOVABLE BAG LINERS FOR TEMPORARY STORAGE CONTAINER
- EVALUATE FEASIBILITY OF DESIGN WITH FLIGHT OF PROTOTYPE

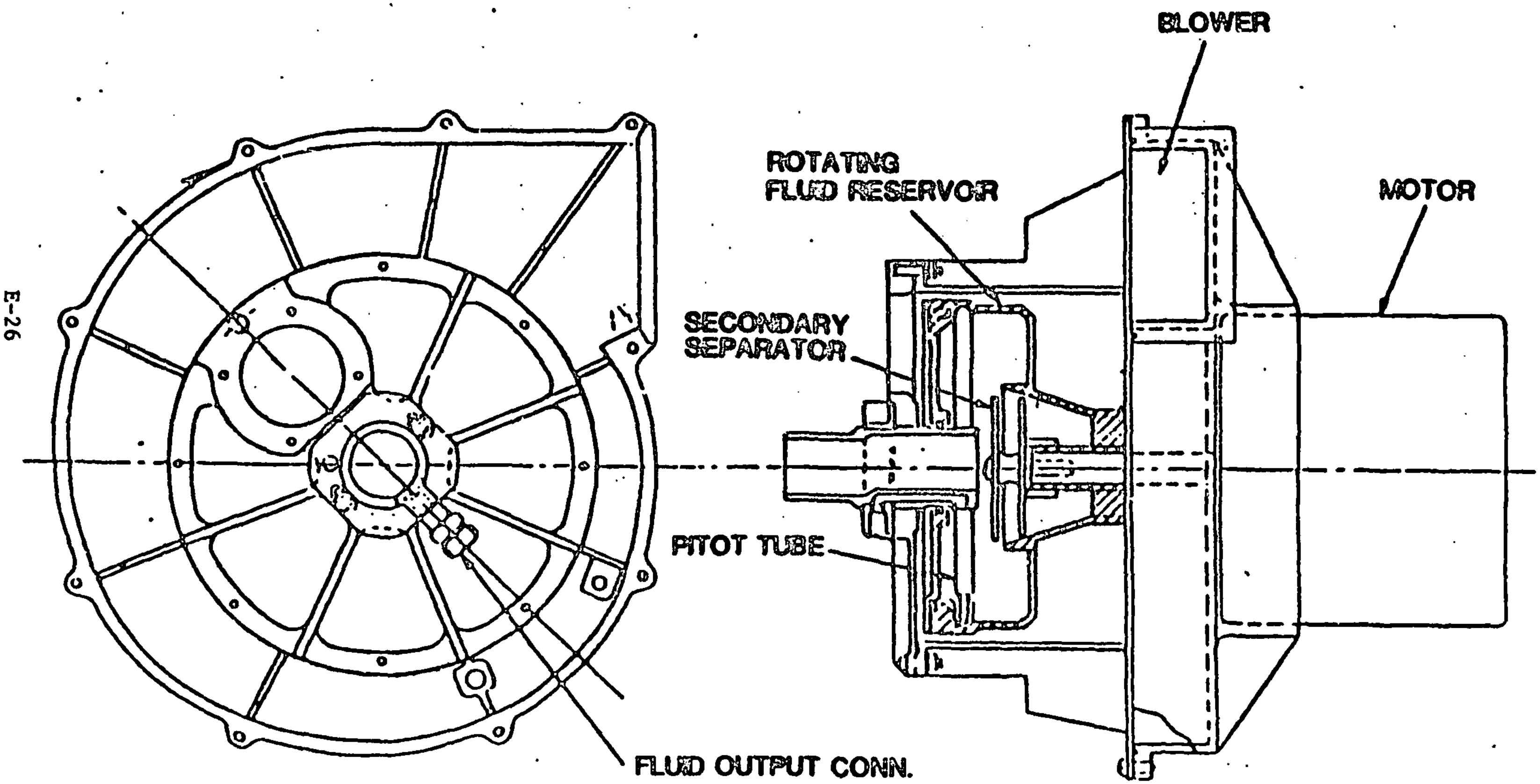
EAGLE ENGINEERING, INC.

FAN/WATER SEPARATOR

- O POTENTIAL FAN/WATER SEPARATOR PROBLEMS
  - SOLIDS BUILD-UP OR FOREIGN MATERIAL BLOCKAGE OF PITOT TUBE
  - LIQUID FLOW VOLUME
- O DESIGN OPTIONS
  - INCREASE PITOT TUBE INLET DIAMETER
  - ADD ADDITIONAL PITOT TUBE IN EACH SEPARATOR

ENGINEERING

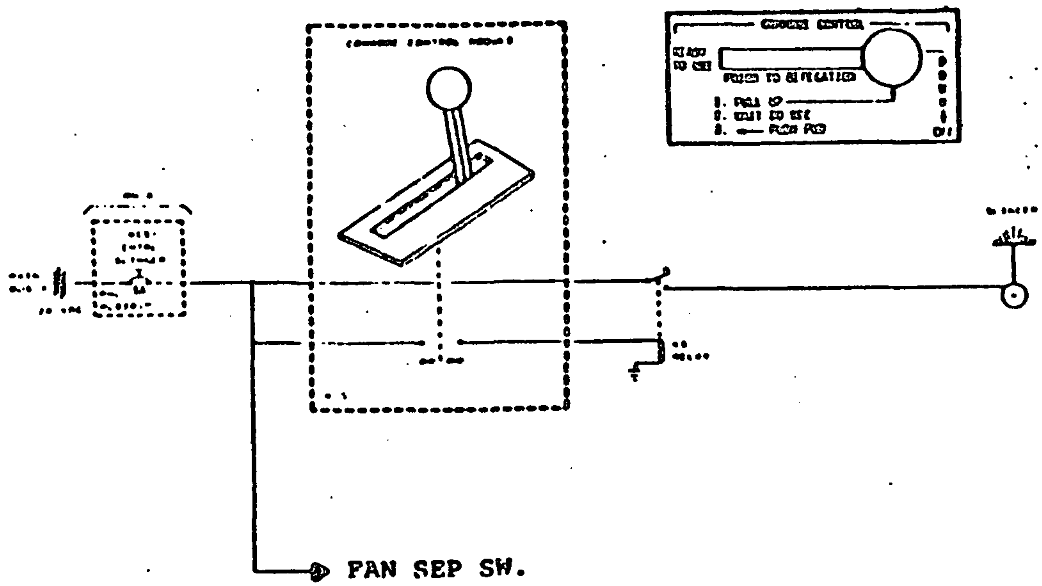
Fan Separator Assembly



EAGLE ENGINEERING, INC.

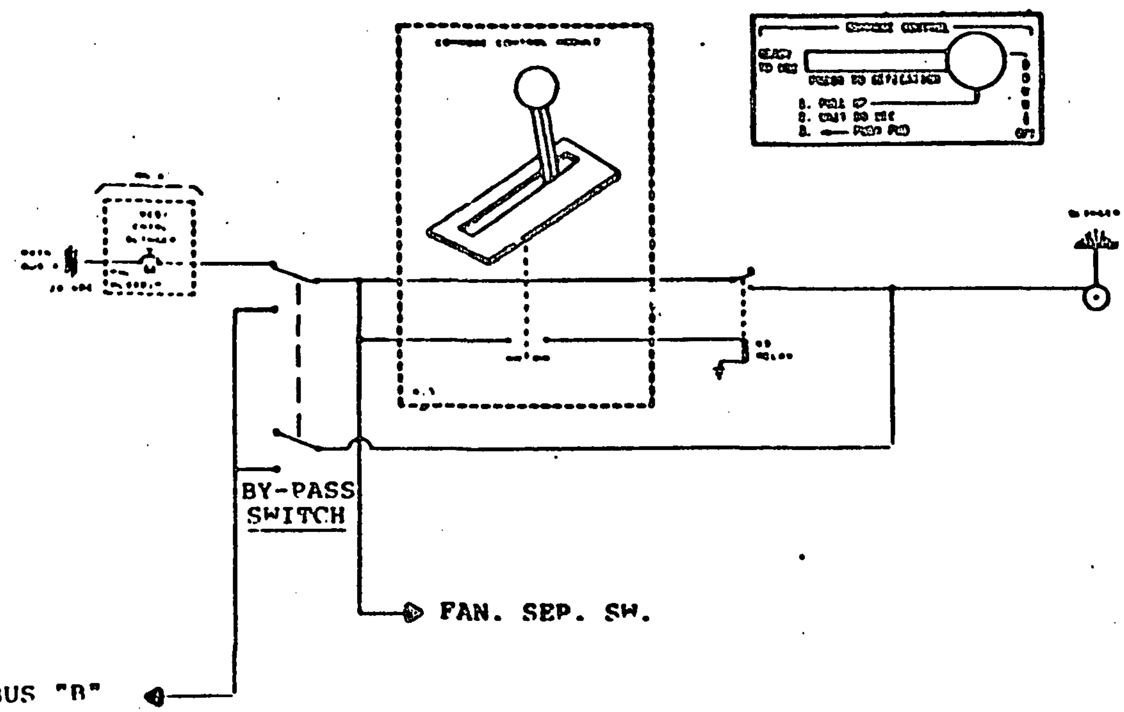
ELECTRICAL DESIGN IMPROVEMENT IDEAS

Current Slinger Electrical Curcuit

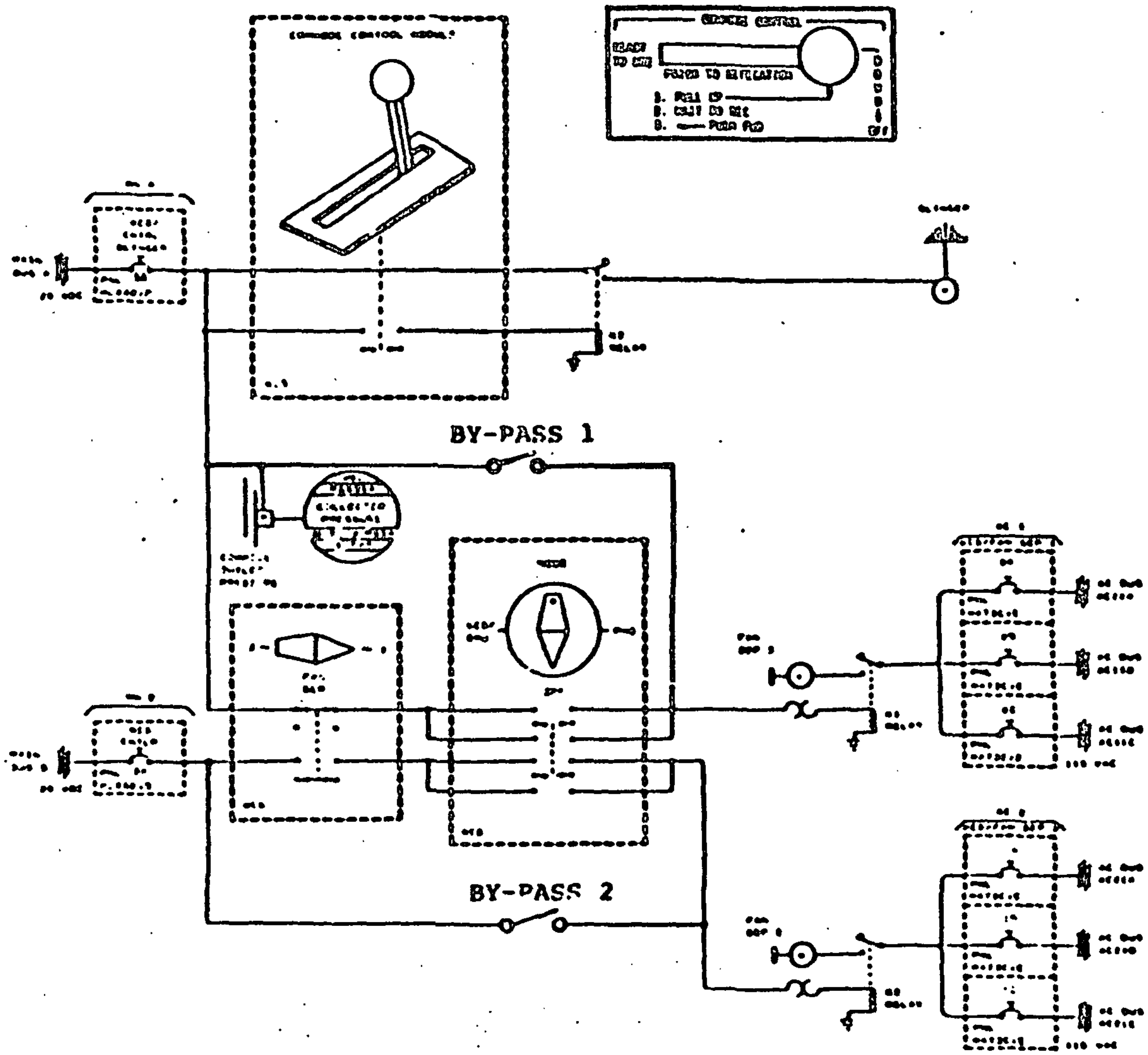


ENGINEERING

Proposed Slinger Electrical Circuit



Current Electrical Power Design



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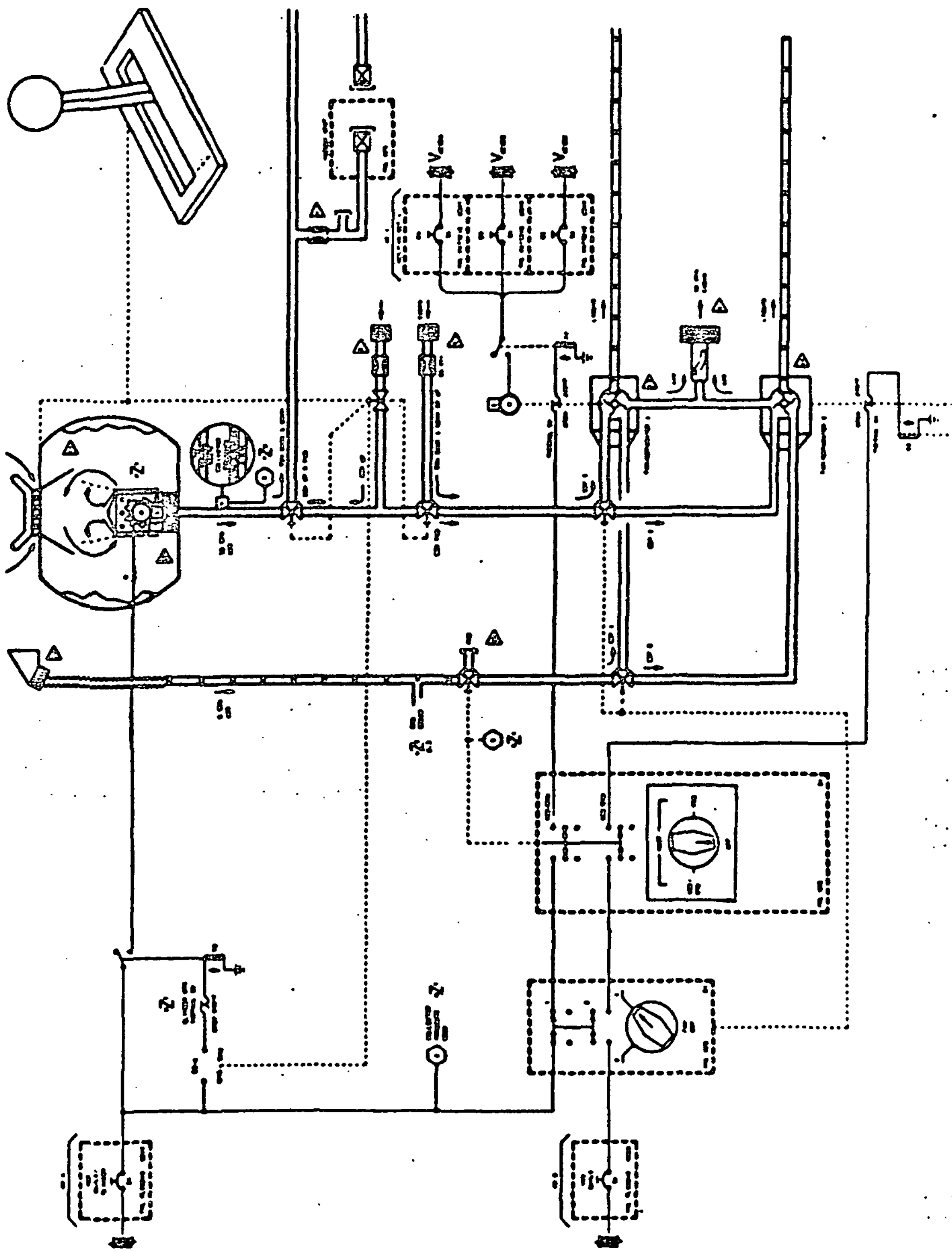

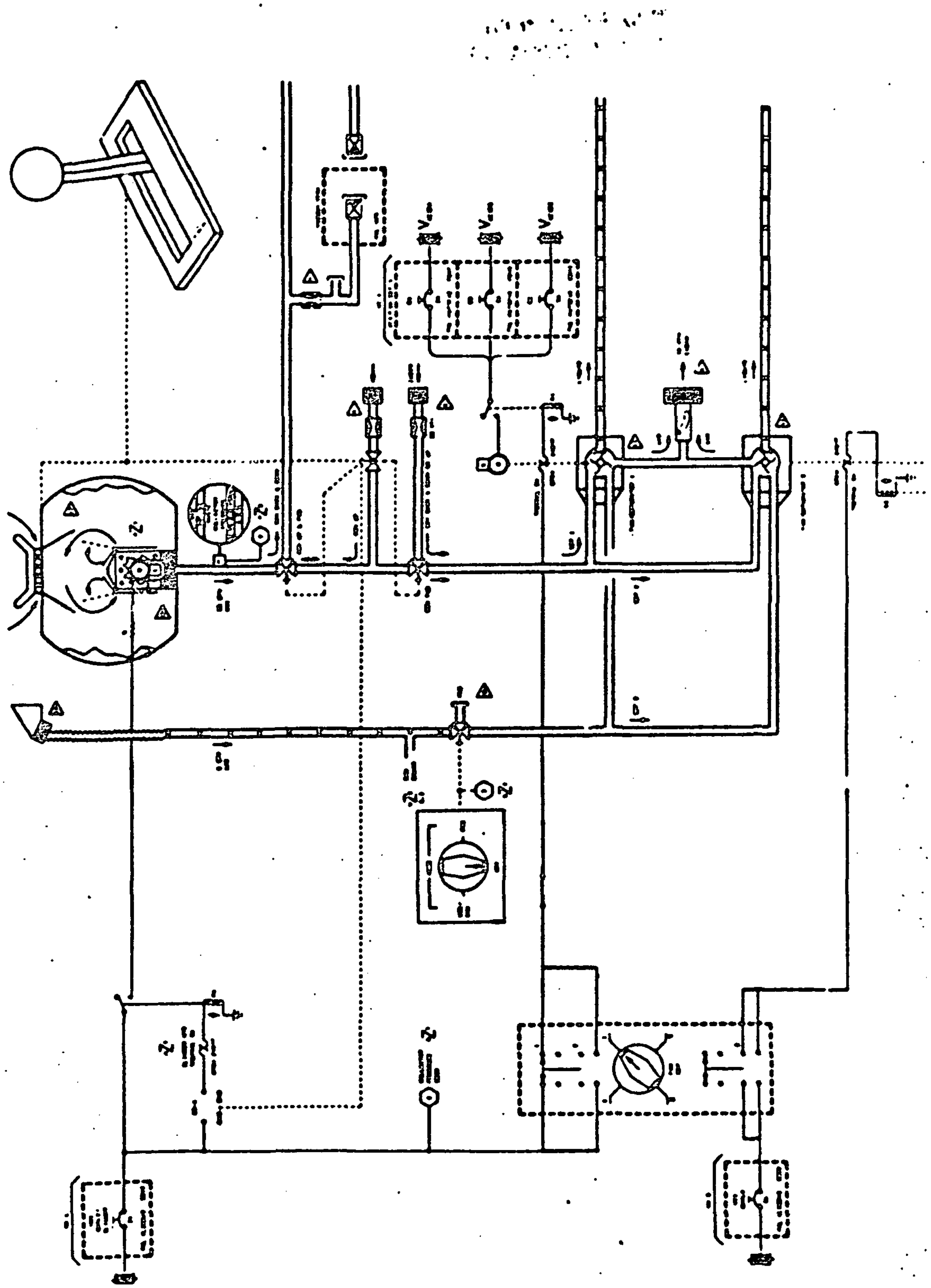

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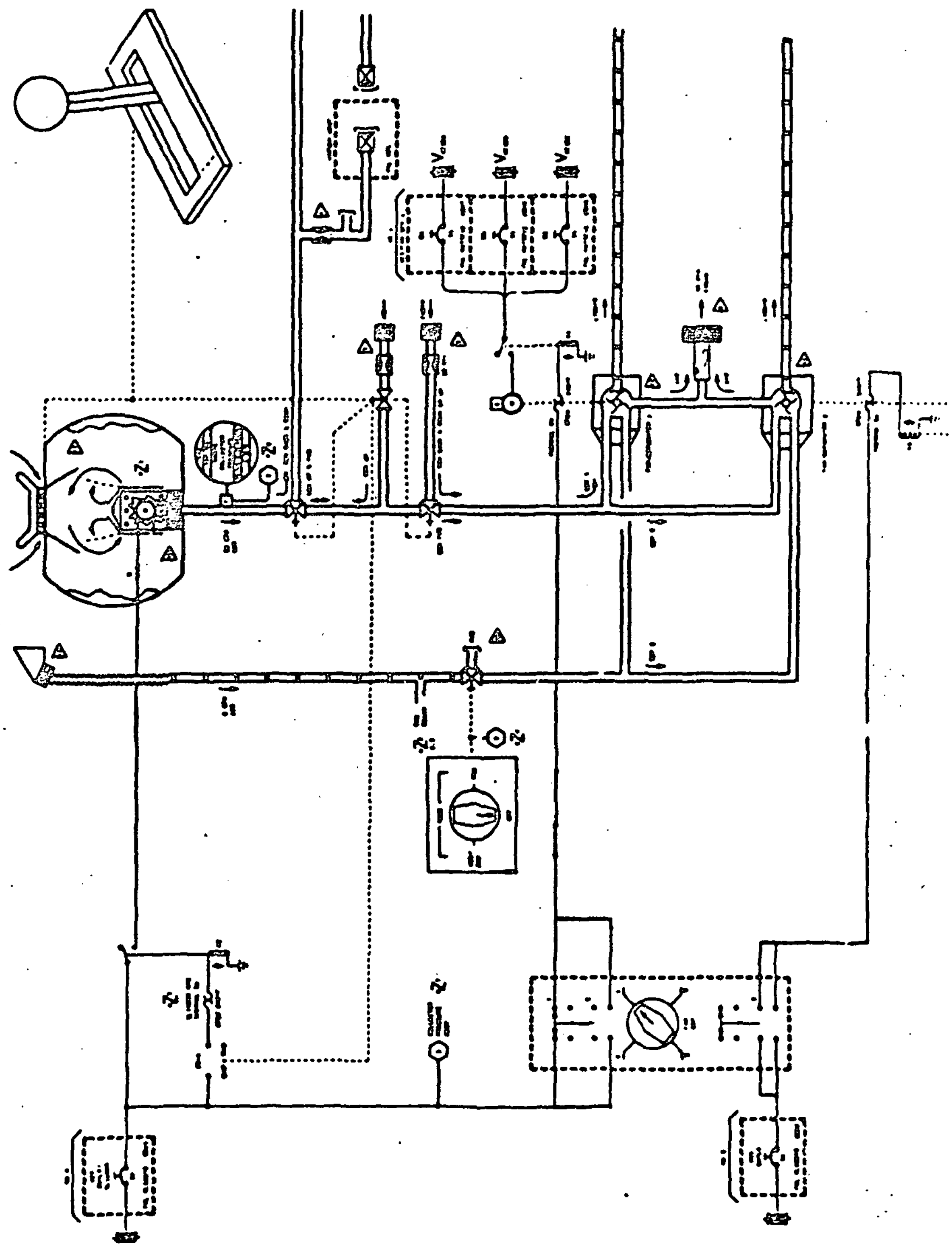
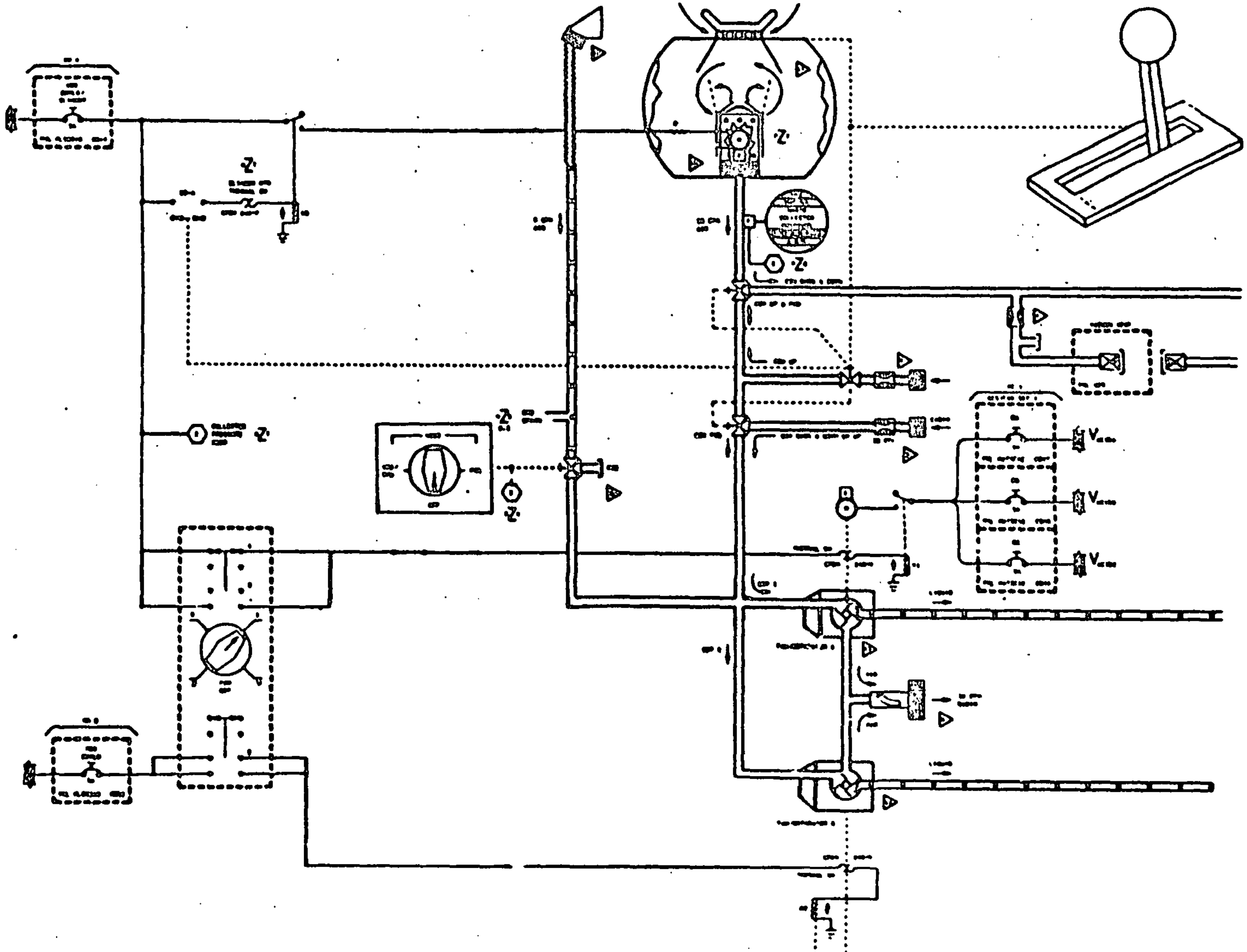




EAGLE ENGINEERING, INC.

NEW DESIGN IDEAS

EAGLE ENGINEERING, INC.

NEW WCS DESIGN CONCEPTS

- O GROUND RULES
  - WCS MUST FIT WITHIN EXISTING VOLUME CONSTRAINTS
  - SYSTEM DESIGN REQUIREMENTS APPLY
- O LOOKING AHEAD TO SPACE STATION
  - SPACE STATION APPLICATION ASSUMES SERVICING AFTER 210 MAN-DAY OF USAGE
  - SERVICING MUST BE ACCOMPLISHED ON SPACE STATION

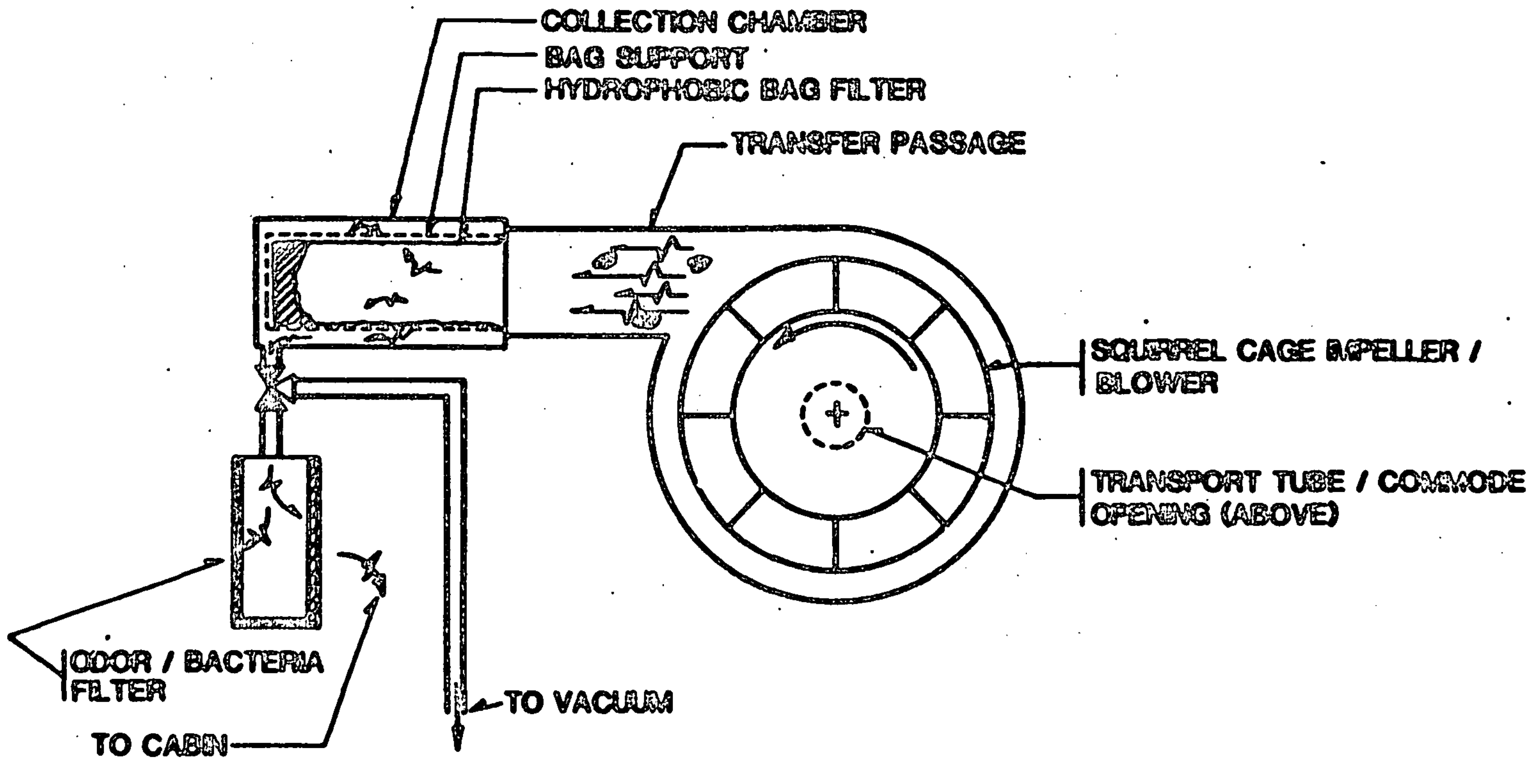
EAGLE ENGINEERING, INC.

NEW WCS DESIGN CONCEPTS

(CONTINUED)

- O DESIGN OPTIONS
  - WCS WITH REMOVABLE FILTER BAG
  - BASE LINE WCS WITH SEPARATE WASTE PAPER STORAGE
  - WCS WITH INTERNAL MECHANICAL COMPACTOR
  - BIDET TYPE OF WCS
  - INCINERATOR
- O SPACE STATION
  - LIQUID TRANSPORT, TREATMENT, RECOVERY

Squirrel Cage



(PLAN VIEW)
NO SCALE

EAGLE ENGINEERING, INC.

SQUIRREL CAGE

PRO'S AND CON'S

PRO'S	CON'S
o HIGH CAPACITY	o NOISE
o HIGH AIRFLOW	o COSTLY
o GROWTH TO S.S. APPLICATION	
o NO NEW TECHNOLOGY	

EAGLE ENGINEERING, INC.

RECOMMENDATIONS

- O EVALUATE WCS PERFORMANCE ON FLIGHT 41-D
- O SELECT BASE LINE WCS CONFIGURATION
- O DETERMINE IF SEPARATE STORAGE OF WASTE TISSUES IS DESIRABLE
- O PROCEED WITH DEVELOPMENT OF IN FLIGHT SERVICEABLE WCS
- O INCORPORATE DESIGN IMPROVEMENTS IN FAN/WATER SEPARATOR

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ENGINEERING, INC.

QUESTIONS & RESPONSES